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EDUARD ŠEVTŠENKO Intelligent Decision Support System for the Network of Collaborative SME-s

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Intelligent Decision Support System for the Network of Collaborative SME-s

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Declaration: Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any other degree.

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MASINA- JA APARAADIEHITUS E39

Intellektuaalne otsuste toetamise süsteem väikeste ja keskmiste ettevõtete koostöövõrgustikule

EDUARD ŠEVTŠENKO

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KIRJASTUS

CONTENTS

INTRODUCTION

The past few years have showed an increasing interest of companies in a close cooperation with other partners. Under pressure from global competition, small and medium-sized companies have particularly been determined to set up cooperation networks. The competition in business has changed from “company versus company” to “business network versus business network” [1]:

In the real conditions of Estonian economy, there is a trend towards implementing new technologies in production and service sectors. For this purpose, it is important to start up a research project in the area of enterprise collaboration, and to determine the aspects that could be usable under Estonian conditions. Collaboration should increase the competitiveness of Estonian market on EU markets, due to the use of additional possibilities and resources achieved through the collaboration. The concurrency of enterprise network over single enterprise is as much stronger, as concurrency of a team over the single person. In this research work, the existing structures of collaboration will be analyzed and new collaboration possibilities will be proposed on the basis of result’s analysis.

The research addresses the needs of Collaborative Network of production enterprises. The main idea is that there must be an Intelligent Decision Support system in the network of collaborative enterprises, which will be able to work with different Enterprise Resource Planning systems and different databases that are used in the enterprise network. The role of the human will be to assess the proposals prepared by the systems and to make the decisions; the role of the system will be to suggest the best solutions, which will be based on current conditions. This work was carried out at Tallinn University of Technology (TUT) in cooperation with the University of Central Florida (UCF). The main concept was developed in TUT and presented at international conferences. The comprehensive literature review and the selection of methodology were performed by the author at the UCF. The journal papers VIII, X, XI were written in cooperation with assistant professor Yan Wang.

The objective of this research work is to propose a new type of framework for decision making in collaborative network of enterprises. This work presents the novel vision of Intelligent Decision Support system, describes the methodology used and presents the results of analysis of computational experiments performed. The new system enables enterprise networks to be less dependent on the personal experience of employees, to grow and to store enterprise’s main weapon among competitors – the knowledge.

The thesis is structured in the logical order. The first part includes the literature review, which describes what already has been done in the field of enterprise collaboration, data mining, review of different information systems and the techniques that are used for decision-making.

The second part describes which ERP and DSS systems have been tested and proposed a new framework for collaborative decision support. The IDSS (Intelligent Decision Support System) model for management of collaborative enterprises is developed to support efficient collaboration between enterprises. The system enables you to manage the internal and external data circles of collaborative network of enterprises. Also the decision support methods are selected for solving specified tasks. Selected methods are Linear programming, AHP, ANP, Decision tree and Bayesian Network (Figure 1).

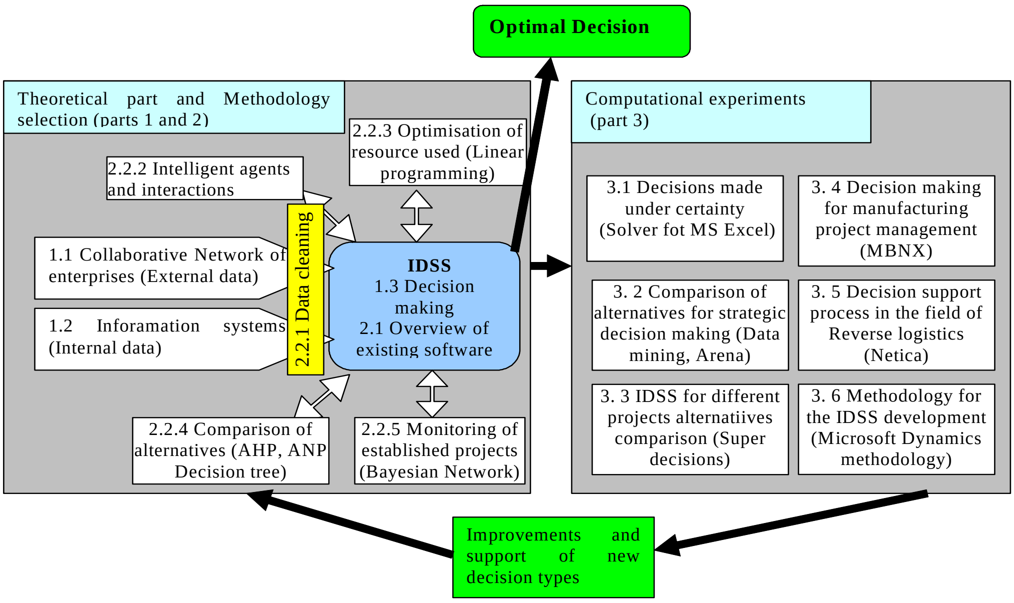

Figure 1. Structure of the thesis

The third part presents computational experiments performed by different Decision Support systems: Solver, Super decisions, Palisade, Netica and MBNX (Figure 1). Experiments are related with collaborative decision support performed in different fields by using selected methodologies:

Methodology for comparing alternatives on a strategic level is developed. Different projects, products, customers, etc. are compared and the best choice is proposed by decision support software. It is introduced how the system performs decision making under the conditions of available information and existing constrains. The system supports collaborative decisions in the conditions of uncertainty. The Analytic Network Process methodology is selected for this type of decision-making process and computational experiment is performed by the Super Decisions software developed by Dr. Thomas Saaty.

The vision of real time monitoring of established projects is developed. When the decisions are made, the system is able to track situation on the base of the last information available. The system acts in a way of monitoring the real situation and provides an alert to the users if the real situation is going out from the planned boarders. Management based on real time data is more efficient than management based on received reports. In such way, the gap between the availability of information and corrective actions performed is decreased. The Bayesian network methodology is selected for this purpose and the computational experiment is performed in Microsoft Bayesian Network Editor software

The vision of operation level management decisions support is proposed. In case, when there is precise information, the system is able to optimize the performance in the condition of existing constraints. It is possible to assess how the situation could be changed, and what results are predicted after the changes are made to the system. The simulation can be used for analysis of predicted result after the changes are made to the system. The linear programming model methodology is used for this purpose. A computational experiment is performed using Solver software Excel spread sheet simulations and arena simulation software.

Reliable IDSS framework methodology under uncertainties is proposed in order to maximize the net product lifecycle asset value recovered from the flow of returned products. It is proposed to consider a range of situations, instead of one situation, during decision-making. The intervals are used to represent uncertainties and to consider all possibilities of variations in the worst cases, in combination with probabilities that address variability. Robust Bayesian networks are applied to compute imprecise posterior probabilities to increase the robustness of IDSS.

The vision for decision support system development and implementation is proposed. The dynamic implementation methodology is suggested for this purpose. During the system implementation the existing experience in ERP consulting is used.

ACKNOWLEDGEMENTS

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Estonian Science Foundation (grants no. 6795 , 5620) is acknowledged for supporting my research. Archimedes Foundation, and Tallinn University of Technology are acknowledged for covering my travel and living costs abroad.

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Finally, I would like to thank my family and friends for their continuous direct and indirect support, patience, understanding and encouragement at different stages of the present work.

ABBREVIATIONS

ABC	– Activity Based Costing
AHP	– Analytic Hierarchy Process (AHP) is a special case of the ANP
AI	– Artificial Intelligence
AM	– Agile Manufacturing
ANP	– Analytic Network Process
ANN	– Artificial Neural Network
AP	– Aggregate Planning
BBN	– Bayesian Belief Network
BI	– Business Intelligence
BOM	– Bill Of Materials
BPR	– Business Process Reengineering
CAD	– Computer-Aided Design
CAM	– Computer-Aided Manufacturing
CAPP	– Computer-Aided Process Planning
CASE	– Computer-Aided Software Engineering
CE	– Concurrent Engineering
CIM	– Computer Integrated Manufacturing
CLM	– The Council of Logistics Management
CNM	– Combinatorial Neural Network
CSP	– Constraint Satisfaction Problem
DBMS	– Database Management System
DCF	– Discounted Cash Flow
DEDS	– Discrete Event Dynamic System
DM	– Data Mining
DM-NN	– Data Mining-Neural Network
DSS	– Decision Support Systems
DT	– Decision Theory
EAI	– Enterprise Application Integration
EMV	– Expected Monetary Value
ENS	– e-Negotiation Systems
ERD	– Entity Relationship Diagram
ERP	– Enterprise Resource Planning
EVSI	– Expected Value of Sample Information
EVPI	– Expected Value of Perfect Information
EV	– Expected Value
FEO	– For Exposition Only diagram

FMS	– Flexible Management System
FSD	– Fuzzy Synthetic Decision Model
GBR	– Generalized Bayesian Rule
ICAM	– Integrated Computer-Aided Manufacturing program
ICOM	– Input, Control, Output, Mechanism
IAS	– Intelligent Advisory System
IDEF	– Integrated Definition methodology
IDSS	– Intelligent Decision Support System
IDMSS	– Intelligent Decision Making Support System
IICE	– Information Integration for Concurrent Engineering program
IMS	– Intelligent Manufacturing Systems program
IRR	– Internal Rate of Return
ISD	– Information System Development
IT	– Information Technology
LP	– Linear Programming
MAS	– Multiagent Systems
MIS	– Management Information System
MRP	– Material Requirements Planning
MRPII	– Manufacturing Resources Planning
NGM	– Next Generation Manufacturing Project
NN	– Neural Network
NPV	– Net Profit Value
NSS	– Negotiation Support Systems
NSA	– Negotiation Software Agents
OEM	– Original Equipment Manufacturer
PBP	– PayBack Period
RAI	– Return on Average Investment
ROI	– Return on original Investment
SADT	– Structured Analysis and Design Technique
SDLC	– Software Development Life Cycle
SME	– Small and Middle Enterprises
SQL	– Structural Query Language
UML	– Unified Modelling Language
VM	– Virtual Manufacturing

1 REVIEW OF THE LITERATURE

1.1 Terms related to collaborative network of enterprises

Cooperation - the joint action of several actors on a mutual task [1]. Another *business-related definition* of the term *cooperation* has been developed by Liestmann [2]. According to this definition, cooperation is the purpose-oriented collaboration of two or more companies aiming at one or more objectives. The economic and legal independence of the companies largely remains. Commonly used synonyms for the tern cooperation are strategic alliance or strategic network.

The general requirements of cooperation are *communication* and *coordination*. Communication determines coordination while the cooperation requires extensive coordination [2].

Production networks - the collaborative network of production enterprises [3].

Communication is the transmission of information between actors of the system [3].

Coordination is the alignment of single activities, which enables to avoid double work or repetition of tasks [3].

The *economies of scale*-effect describes the reduction of production costs while increasing the production amount [1].

Economies of scope exists when multiple products can be produced at a lower cost in combination as they can separately [1].

If one company manages to reduce the total lead time below the value of its competitors the sales will be probably increase, described by the term *economies of speed* [5].

Merger is the total integration of companies. *Takeover* is the buying of one company by another one [1].

A *joint venture* is a business run by two or more partners that each holds more or less equal shares in the joint company [1].

The *strategic network* is a newer form of cooperation. It consists of economic dependent but legal independent partners that collaborate on the basis of common strategic aims. The relationships between the partners of such a decentralized network are market-driven, but more cooperative than competitive, and also comparatively stable. A common target of strategic networks is the optimization of the value added chain [1].

The term *outsourcing* describes the purchasing by a firm of material, assemblies and other services that were initially done within the company [1].

1.1.1 Collaborative network of enterprises

There is much in the literature regarding the visions of collaborative networks and methodologies to improve performance of collaboration. Examples are researches connected to the subject of collaborative networks. Could be mentioned the Industrial Innovation Transition and collaborative enterprise vision developed by Tampere University of Technology; Collaboration Management process and cycle of cooperation developed by Aachen University of Technology [3].

In previous research works, business information was presented as database that maps the state of the production system. The input of this business information database is the different companies of production network. Based on this data, calculations are performed to produce the information that is required to run production network. The general process of processing information consists of the three steps "Monitoring and evaluation", "Planning" and "Controlling" networks [1].

Collaborative network of enterprises is actual topic. There are different visions of the production enterprise networks, but there is little information about systems, which will be able to manage the information flow in such collaborative networks [1].

1.1.2 Cooperation objectives

In general, the aim of setting up strategic networks is the reduction of uncertainty and the increase of competitiveness. To make sure that critical partners from whom the company is strongly dependent stick to their commitments, cooperation networks are implemented. The partners of network try to integrate their business and the speed of the product development, the operations planning, the production, and the product distribution can be enhanced. The final result is higher competitiveness that reduces the feared of uncertainty. A target system of cooperation among Small and Medium-sized Enterprises (SME) has been defined by Liestmann [2]at the Research Institute for Rationalization (RIR) at [4] Aachen University of technology management.

Another target of cooperation is the economies of scale according to CHASE [4].

The increasing turbulence of the business environment sets company leaders under high emotional pressure. Rapid changes in the markets, such as mergers, takeovers or joint ventures can have significant influence on the competition. A global player dominating a market can nowadays quickly loose its strong position to cooperating competitors [1].

1.1.3 Cooperation types

Companies regularly investigate their own performance weaknesses. If cooperation is considered as an optional, there still remains the question of which cooperation type or form will deliver the required results [1].

The laboratory for Machine Tools and Production Engineering at Aachen University of Technology has developed a simple classification of typical cooperation types: merger, joint venture and outsourcing [5].

Therefore, the processes, such as the material flow, and the competencies of the network partners determine the general network structure. According to KLINK [6], the tree-, bus-, star-, and ring networks can be distinguished.

The success of a cooperation project is eventually dependant on the cultural fit. While technologies can be bought, it is far more difficult to change the company culture. A strategic network can be global as well as international (continental), national or regional. If the facilities are located closely, the collaboration will be easier than in a global network where cultural problems become more imminent. Considering human resources, soft factors, such as the ability and willingness to communicate and collaborate are often neglected although they are critical for a successful cooperation. A measurable benefit of the common-added value secures the commitment of each partner that forms the basis for mutual trust [7].

1.1.4 Conclusion of section 1.1

Collaborative network of enterprises is more efficient than single enterprise, but there are a lot of problems which needed to be solved before effective collaboration can be started. When new collaborative network is established it is required to find the objectives that will satisfy all participants. The type of the network is related to location and quantity of collaborative partners. The aim is to create informational system to manage knowledge in the collaborative network. Next chapter will give an overview about informational systems in general and special attention will be given to ERP.

1.2 Information systems

Any system that we think about necessarily exists in our thoughts, rather than in the world, and such a system, however, how much it corresponds to the world, is still a subjective view of reality, not the reality itself [8].

Systems have interactions with their environment. Each interaction is based on a set of inputs originated outside the system, and are taken in to be used in some way. Outputs are created by the system and sent into the environment in order to gain an effect somewhere else, but always to serve a purpose of the system [7].

Designing and building the technology can be the easy part of the job at least the easy part to understand, while the hard part is often determining the needs that the technology must serve. This involves identifying ways that an information system can support the purposes of a human activity system. An understanding of the information that will be useful to the human actors is an important ingredient in this, as is an understanding of how the information can be used effectively. As a result of this many different concerns, information systems has become a multidisciplinary subject that bridges many other fields, in particular computer science and business management, but also psychology, social theory, philosophy and linguistics, among others [7].

Information is conveyed by messages and has a meaning. The meaning always depends on the perspective of the person who receives a message. We are always surrounded by a vast mass of potential information, but only some of this ever comes to our attention, and only some of that is actually meaningful in our present context. There is a final step where information becomes *knowledge,* when it is structured into more complex meanings related by a context [7].

Spanning the series of revolutionary changes in computer technology and hardware has been an ongoing evolution of software and methodology. This evolution has been motivated by the intent of harnessing raw computing power as a mean for increasing human productivity and enhancing organizations competitiveness. The result is a vast array of computer systems in today organisations. Two of the most important types of these systems are information systems and decision support systems [9].

It is still helpful to present a brief overview of some of the general types of application in organizations; the following is intended to introduce some aspects of the role of information systems, rather than to depict actual systems.The information systems can be grouped by roles: operational systems, management support systems and real-time control systems [10].

1.2.1 Operational systems

Operational systems automate the routine, day-to-day record-keeping tasks in an organization. The earliest commercial information systems were operational ones, because routine, repetitive tasks that involve little judgement in their execution are the easiest to automate. Accounting systems are one example. These derive from the need in all organizations to keep track of money-the amount coming in, the amount going out, the cash available to be spent and the credit that is currently available. Few modern organizations could survive long without a computerized accounting system [10].

1.2.2 Management support systems

Information systems intended to support management usually work at a much higher level of complexity than operational systems. But the blurring of boundaries in recent years has had particular effect here. For example, the personnel planning application could be considered as management support rather than operational. Moreover, much of the information used by management to make decisions is derived directly from information stored at the operational level. In practice, many management support systems are built on top of operational systems, while other systems combine elements of the two, meeting a complex set of needs at different levels of the organization.

Many of the earliest management support systems were developed simply by adding a set of programs (known as a Management Information System, or MIS) to extract data from existing operational systems, and analyse or combine it to give managers information about the part of the organization for which they were responsible.

This information is useful to managers because they have a responsibility to maximize the performance of an organizational sub-system. An important part of this is identifying and resolving problems as they occur. Thus, the crucial aspect of a management support system is the feedback or feed-forward that it provides, alerting managers to problems and opportunities, and assisting them in the process of tuning the organization's performance [10].

1.2.3 Real-time control systems

Real-time systems are explicitly concerned with the direct control of a system's operations, often physical in nature. For this reason, they are perhaps best considered as a control sub-system of a physical processing system. Their role is thus very different from both operational and management support systems. Real-time systems usually have human operators (to date, few are completely independent of human supervision, though this may become common in the future), but they are generally insulated from the surrounding human activity system. In fact, many authors would not agree that real-time systems are information systems at all. It is regarded as an important issue. The techniques used for the analysis, design and implementation of real-time systems are very similar to those used for other computer systems, so in practical terms any distinction is artificial.

The real time control systems can be also subdivided to functional information systems, enterprise information systems and trans-organizational information systems.

A functional IS is the one that performs record keeping and reporting related to some function of an organisation such as production, finance, accounting, marketing, sales, purchasing, logistics, personnel or research.

Enterprise IS-s cross traditional functional boarders. They keep records pertinent to multiple organizational functions, maintaining them in a consistent fashion and producing both functional and cross-functional reports. Over the past decade, several vendors have successfully offered configurable off-the-shelf software that functions as a tool for building enterprise IS-s. These are known as Enterprise Resource Planning system (ERP system). Most ERP products offer a similar set of features; there are wide variations in the way the features are designed and the level of depth to which they are modelled in Figure 2. It is at the nuts and bolts level that a lot of packages fail. These issues come out only when implementation starts, and often leads to delays in terms of customisation, or worse still, the customer making do with a convoluted 'work around' [1].

The user of IS has a choice between creating or obtaining custom-build IS software and acquiring ready-made software. Customized constructions have the advantage of being tailor-made to suit the user’s needs exactly, but it tends to be time-consuming and expensive. Ready-made software is quickly available and relatively inexpensive, but the behaviour of on off-the-shelf software package may not match the IS users needs or desires. A gold middle between custom-made and ready-made software is package software that can be configured to behave in a certain way. The user selects the particular IS behaviour that most closely suits his needs [10].

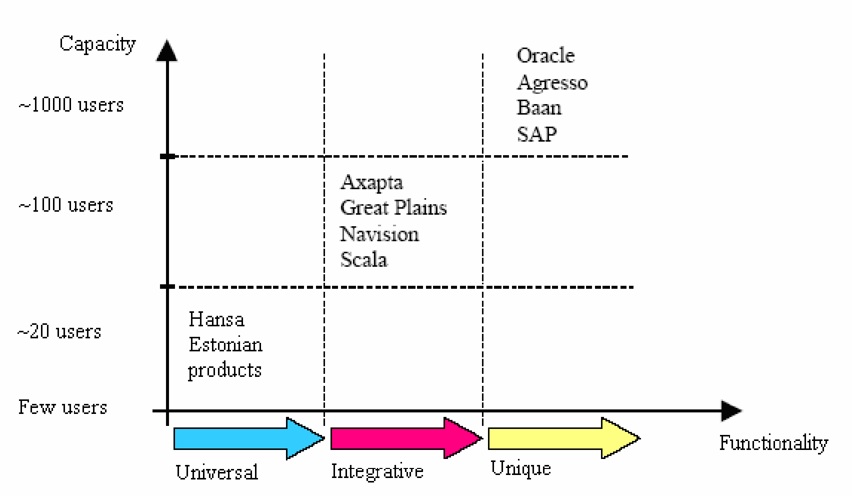

Figure 2. Functionality of ERP systems

Trans-organisational information systems are those that involve information flows to and from entities beyond the enterprises boundaries. Information for updating records comes directly from customers, suppliers, partners, regulators and others. All of this trans-organisational activity is either linked to various internal IS-s or designed as an extension of enterprise IS-s. Especially notable examples are supply chain management systems and Customer Relationship Management systems. Configurable off-the-shelf software for building each of these is available, in some cases allowing them to be treated as additional ERP modules [10].

When performing experiments to find all possible complex compounds that might work for a certain task, scientists want early testing indications of what components may work so they can focus resources. At the same time, researchers want to visualize how it's playing out statistically so they can imbue decisions with their own wisdom. Our data warehouse and analysis software is way ahead of our ability to use it organizationally [10].

1.2.4 Conclusion of section 1.2

It is shown that existing ERP systems are not able to manage the collaborative network of enterprises efficiently. The aim of this research thesis is to work out new possibilities for improvement the effectiveness of ERP systems through adding the intelligence feature. It is important to share both: the practical experience and theoretical know-how in order to obtain maximum efficiency from using the ERP software. New system should be able not only to hold real time data, but also to support decision-making process based on this data. However, such system needs clean data or knowledge for decision making process. Next chapter will describe how the data could be transformed into the knowledge.

1.3 Decision-making

1.3.1 Introduction to decision-making

Basically, the manager is the decision maker. His responsibility is to find out all the information he needs and to make a final decision. Although the decision-making is very complicated process, the manager is still needs to take into consideration all factors. It was observed that the problems that trigger decisions are not factual data but constructs. Author parsed the decision making task into the following parts: identify all the possible alternatives; determine all the possible consequences of these alternatives; evaluate all the possible consequences [11].

Limitations that apply to human cognition and formulate a number of assumptions that became the foundations of what, in 1955 was termed “bounded rationality”. It was concluded that managers must content themselves with suboptimal or “satisfying” decisions. In practice, given these limitations, the decision process stops when decision makers reach a solutions that satisfies them within what appears to them to be the most probable hypothesis [12]. Also, it is frequently opposed by procedural rationality – the rationality that takes into account the limitations of the decision maker in terms of information, cognitive capacity and attention - to substantive rationality, which is not limited to satisfying, but rather aims at fully optimized solutions.

There is a large body of literature about systems that are able to support decision-making processes. These systems are named Decision Support Systems (DSS) or Decision Making Support Systems (DMSS) or Enterprise Information System (EIS). Relatively recently some DMSS and EIS-s address the information gathering phase by aiding the decision maker in data mining and extracting information from databases and data warehouses, by proposing better interface designs to help managers in searching. What people need in most situations is less, not more, information; and what Intelligent Decision Making Support System needs to provide the first and the foremost is the facilitation of action not the accumulation of knowledge. It is proposed a five-step method consisting of problem setting, bricolage, coordination, narration, and simulation [12].

The secret of problem solving is, of course, that there is no secret. When no finite algorithm can be found for a decision-making situation, the only remaining solution is to carry out a heuristic search for a desirable solution. Each heuristic search within the overall search for a solution that satisfies criteria is based on two main components: evaluation, to assess the current state of the search and decision, to select the most desirable goals or sub-goals to move towards [12].

A methodology for the ranking of measures in a DSS has been developed in order to support policy makers to make a strategic selection between different measures while taking uncertainty into account. The methodology consists of an uncertainty analysis and a ranking procedure based on significance of the difference between output distributions.

Four of the decision-support items concern objectives of supporting various types of decision situations: (1) one person making individual decisions; (2)

multiple people jointly contributing to making a decision; (3) multiple people involved in making inter-related decisions; and (4) people both inside and outside of an organization involved in making cooperative or negotiated decisions [13].

Because of the proliferation of the Internet and global networks, organizations are increasingly connected to one another, not only for the purpose of transacting and exchanging data but also for making collaborative or negotiated decisions. ERP systems can serve as platforms for trans-organizational exchange [14].

Decision-support benefits have been identified and discussed by several DSS researches, although not in connection with ERP systems. They concluded by advancing eight ways for gauging DSS benefits: overall cost effectiveness of DSS, overall user satisfaction with the DSS, degree to which a DSS enhances company competitiveness, degree to which a DSS enhances communication within an organization, degree to which a DSS enhances user productivity, degree to which a DSS provides time savings, and degree to which a DSS reduces costs. The relatively unified, consistent, common, real-time knowledge repository resulting from ERP implementation is a foundation for realizing practically all specific decision-support benefits [14].

Intelligent systems provide advice to the end user to assist in decision-making and problem-solving. One criticism levelled against these systems is that they are rigid dialogs that are hard to understand. In Expert systems, for example, it is hard to understand how a given set of inputs produced a recommendation by the system. Explanatory power refers to the ability of intelligent systems to explain its actions. Two related characteristics are relevant to understanding explanatory power: transparency, or the ability to see the underlying mechanism of the system so that it is not merely a black box; and flexibility, or the ability of the interface to adapt to a wide variety of end-user interactions, so it is not merely a rigid dialog, but an open-ended interaction that allows the end user to explore and understand the systems more fully. While transparency of the system is a quality related to the information content of the system itself, flexibility is more related to the nature of the end-user interaction with the system [14].

Content based enhancement focus on augmenting the actual informational content of an intelligent system. Interface-based enhancements relate to the interface design choices that systems designers make to increase the effectiveness of intelligent systems. Hence, a third type of enhancement is the appropriate selection of an advisory strategy, or the manner in which the explanation is delivered to the end user. The three types of explanations that contribute to the overall explanatory power of an intelligent interface: rule traces, strategic knowledge, and deep justifications [15].

Rule traces:

Different types of questions are allowed such as “why-not?” and “what-if?”;

Rules are displayed in a natural language as opposed to computer-generated code;

Rule traces are displayed at the right level of detail.

Strategic knowledge:

The problem-solving strategies are made explicit to the end user (or are available upon request);

The overall line-of-reasoning is made visible to the end user;

The strategic knowledge is appropriately structured for the end user (e.g., a tree of goals, or a tree of topics).

Deep justifications:

An explanation is tied to an underlying domain model that provides structural knowledge (e.g. causal relationships about the domain) and taxonomic knowledge about the domain;

An explanation is tied to underlying domain principles that provide knowledge about methods and heuristics used to problem solving [15];

The modern applied mathematics can produce solutions to many tens of classes of conflicts differing by the composition and structure of participants, specific features of the set of their objectives or interests, various characteristics of the set of their actions, strategies, behaviours, controls, and decisions as applied to various principles of selection or notions of decision optimization [15].

1.3.2 Information collaboration for decision support

For the largest companies today, ERP serves within the core set of day-to-day transaction processing applications. Even when data is efficiently captured and stored in ERP systems, it may remain relatively useless for reporting and decision making purposes. ERP systems do central work of running, tracking and reporting on business data processing [16].

An organization's most valuable business asset flows through its enterprise every day. It is the data from customer orders, purchase receipts, operating statistics, etc. Analyzing received data can provide business insight an organization can't get any other way—insight executives and managers can use this information to guide the tactical and strategic decisions that drive company's performance [16].

The requirements of an enterprise wide Decision Support System can only be met by a system optimized for data access, quality, and integrity. Knowledge is a key organisational resource. Acquiring knowledge is a concern of organisations as most are significantly knowledge–dependent for their success [17].

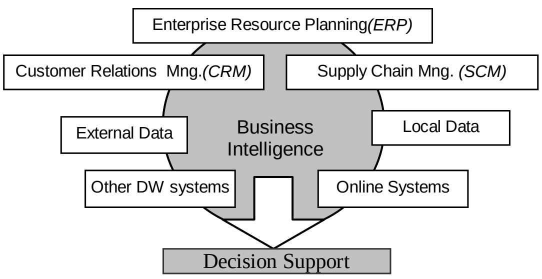

Figure 3. Information collaboration for decision support

Data mining is defined as the nontrivial process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data. The whole process of data mining consists of several steps. Firstly, the problem domain is analyzed to determine the objectives. Secondly, data is collected and an initial exploration is conducted to understand and verify the quality of the data. Thirdly, data preparation such as selection is made to extract relevant data sets from the database. The data is pre-processed to remove noise and to handle missing data values. Transformation may be performed to reduce the number of variables under consideration. A suitable data mining algorithm is then employed on the prepared data to discover knowledge represented in different representation such as decision trees, rules, and Bayesian networks. Finally, the result of data mining is interpreted and evaluated. If the discovered knowledge is not satisfactory, these steps will be iterated. The discovered knowledge is then applied in decision-making [17].

In this context, we can speak about agents. An agent is an independent unit that is able to perform tasks or collaborate with other agents if required. If agents need to act in situations, they put data structures called “situations” in their heads. If agents need to figure out what might happen, it can put simulations of the world in the head. In short, the basic method of mentalism is to reproduce the entire world inside the head [13].

Quite an interesting approach is presented in the way of combining the data mining process and neural networks. The Data Mining-Neural Network (DM-NN) model has a multilayer architecture that can be divided into two levels: data and process. Specifically, data –mining technology was chosen to induce expert-domain knowledge from historical databases, hence minimizing the difficulties of acquiring expert domain knowledge, and Artificial Neural Network (ANN) based system is employed to implement learning and reasoning with the knowledge obtained through data mining. The employed Artificial Neural Network system also provides explanatory capabilities, and the user interface level. The DM-NN model was applied in aviation weather forecasting; as such, in this research cases are series of weather observations [7].

Since the introduction of the term “data warehousing”, companies have explored the ways they can capture, store and manipulate data for analysis and decision support. Data warehouses differ from traditional transaction databases in that they are designed to support decision-making rather than simply efficiently capture transaction data [7].

1.3.3 Decision making methodologies for collaborative network

There are a huge amount of methodologies that are able to support decision making process. The methodologies mostly used in the field of decision support are selected. Also it is assessed if they can be used for decision making in IDSS and on what stage. Summary of decision making approaches [11, 12, 13, 14, 15, 18, 19, 20, 21, 22, 23] is represented in the Table 1.

Table 1. Summary of decision making approaches

Approach	Characteristics
Probabilistic Decision Theory (DT)	The decision makers preferences are encoded by the utility function. For maximizing the outcome the decision with the highest expected utility should be selected. This methodology is selected for calculation utility of different decision in IDSS.
Bayesian learning	The Bayesian learning model enables updating the knowledge of beliefs after additional data becomes available. Selected for monitoring function in IDSS after new information is received.
Possibilistic Case-Based Reasoning	The reasoning from previous cases may be performed through a possibilistic rule stating that: "The more similar the situations are the more possible are similar outcomes." Method can be used in IDSS when the history data became available.
Constraint-based reasoning	Used for finding a solution that satisfies constraints of negotiating partners. It aims to find a solution that satisfies all constraints. Could be later used in IDSS system for the decision making under conditions when all constraints are known
Heuristic search	The mechanism allows the generation of offers and counter offers in a responsible way, linearly combining simple functions that are called tactics. Could be later implemented in the IDSS system for the determination of negotiation offer.
Q-learning	This method combines the idea of decision functions and reinforcement learning algorithms into a new approach called Q-learning. Could be later implemented in the IDSS system for exploring the environment through the implementation of actions.
Evolutionary computing	The trial-and-error approach for learning good strategies is evolutionary computing. Could implemented when the IDSS system is implemented for the searching of potential strategies
Analytic Network Process (ANP) AnalyticHierarchy Process (AHP)	The ANP is used in multi-criterial decision analysis. The AHP structure a decision problem into levels forming a hierarch, while the ANP is using a network approach. Those methodologies are selected for comparison of different alternatives in IDSS system.
Linear Programming	The linear programming (LP) problems involve the optimization of a linear objective function, subject to linear equality and inequality constraints. Suitable in combination with MS Excel solver for max profit achievement related decision making under the conditions of known constraints.

1.3.4 Conclusion of section 1.3

For future IDSS different methodologies were selected. It is shown in this chapter that before using the information in decision making process it must be cleaned. Bayesian learning is suitable for update of situation after new knowledge is achieved. It is possible to use this methodology for monitoring purposes. Analytic Hierarchy process approach is convenient for comparison of alternatives during decision-making. Probabilistic decision theory can be used for calculation of probabilities for different event, which will follow the decision made.

2 AIMS OF THE STUDY AND SELECTION OF METHODOLOGIES

2.1 Aims of the study

1. Development of the new model for the management of internal and external data circles in the collaborative network of SME-s
2. Analysis of the tasks performed by ERP and DSS systems
3. Selection of methodologies for the IDSS system: comparing alternatives on strategic level, operation level management decisions support, calculation of imprecise probabilities, monitoring of established projects
4. To perform computational experiments in decision support software: MBNX Editor, Solver for MS Excel, Netica, Super Decsions, Palisade
5. Development of the system development and implementation methodology

2.2 Overview of existing software

Today the market vendors propose different types of ERP and Decision Support Software. It is interesting to make an overview of existing solutions and to understand how they work and how they can enhance the collaboration between enterprises.

2.2.1 The DSS and ERP tested

In general, DSS are designed for independent work. Every system works independently and is aimed to solve particular tasks. It is possible to use software for single user, but it is impossible to use it for collaborative decision-making

Table 2. Tested decision support tools

Name of the Software	Methodology used	Type of decisions	Type of solution	Number of users participated in solution making	Reports
Super decisions	AHP, ANP	Comparison of alternatives	Local user	1	Analytical
Palisade decision tools Precision tree for Excel 1.0	Decision tree, NPV, Bayes rule	Selection of alternative with bigger NPV, risk and sensitivity assessment	Local user	1	Sensitivity analysis, risk analysis
MSBNx	Bayesian network	Decisions making based on prior and posterior information	Local user	1	Bayesian network
Netica	Bayesian network, Decision trees	Making decision based on prior and posterior information	Local user	1	Sensitivity & Utility analysis

The Super decisions software free version was downloaded from Saaty website. Palisade decision tools student version was purchased with the textbook. MSBNx is the free software developed by Microsoft. Netica is free decision support software was downloaded from Netica web site. The list of tested systems is given in Table 2.

The ERP software packages were selected from the mostly used systems in Baltic region are presented in Table 2. The systems are convenient for collaborative work but the decision-making features are quite simple. Mainly, the decision is made based on different modules reports. It is impossible to track the situation in real time, due to the lack of real time monitoring feature. The reports represent the information available in the systems and they represent data for the previous period. If a report is very complicated it must be started when there are no users in the system, otherwise it will disturb the work and the main activities in the system will be slowed down. The research was performed in order to have a clear picture of the ERP market, and available kinds of systems and how they correspond to the needs of enterprises. The "Scala" ERP system basic functionality was reviewed on the base of BLRT Group and production module functionality research was performed during Bestnet Ltd. production module implementation process. Research of "Microsoft Dynamics AXA" functionality assessment was performed for Bestnet Ltd. during the software vendor selection process. "Monitor" was researched in cooperation with Tarkon Ltd., where "Monitor" is successfully implemented for production planning purposes. "Hansa Financials" analysis was performed on Kraana Vaabrik Ltd. enterprise. "Microsoft Dynamics NAV" functionality and Microsoft implementation methodology was approved on Loksa Shipyard, Logistika Plus and Konesko Ltd. enterprises.

Table 3. ERP systems reviewed

Name	Database supported	Integration with other applications	Important parameters / basic features
Scala	Microsoft SQL	Possible	
Monitor	Sybase	Stand alone application	Basically used for manufacturing enterprises
Microsoft Dynamics AXA	Microsoft SQL, My SQL	Integration possible	Basically use for large production enterprises.
Microsoft Dynamics NAV	Navision, Microsoft SQL	Integration is easy	~5000 Verticals are made by Microsoft partners
InVision Software	InVision Enterprise server	Possible through X-Link	Basically used for manufacturing enterprises
Hansa Financials	Own server	Difficult	Basically used for retail and booking enterprises

2.2.2 Integration of ERP and DSS

While ERP systems solved the problem of centralizing disparate data and streamlining business processes, over time they made firms rich in data. This placed demands on the field of DSS to introduce applications that could be integrated with ERP systems. This integration was to serve the purpose of taking this data, turning it into information, and eventually creating knowledge. This brought about the introduction of Business Intelligence (BI) and Analytic Applications in the 1990s. These applications enabled decision makers to obtain enterprise-wide data more easily [23]. ERP systems are mostly used as sources of data for Business Intelligence and analytic solutions.

The integration of ERP and IDSS brings about a number of significant benefits. These include the ability to improve the quality and visibility of information, increase Intelligence Density, and achieve multi-enterprise collaboration [23]. Intelligence Density defines the value of integration ERP and DSS. By using the Intelligence Density conception, it is possible to understand the relative value of various DSS tools and technologies, their integration with ERP systems, in order to provide better decision support for decision makers.

A firm can integrate an ERP system with IDSS in one of several ways: extend the functionality of current DSS so that they can easily access the data stored in an ERP system; integrate existing DSS that currently sit on top of a firms' ERP system; integrate existing DSS that currently sit on top of a firms' ERP system across multiple firms; build a single, flexible, and comprehensive DSS that sits on top of an ERP system [23].

Practically, it is important to take into account that these ERP and IDSS integration options may be achieved via an emerging class of integration technologies called Enterprise Application Integration (EAI) [24]. The other way of ERP and IDSS integration is using integrated agents. Multi-enterprise collaboration framework made by using agents is introduced in Figure 4.

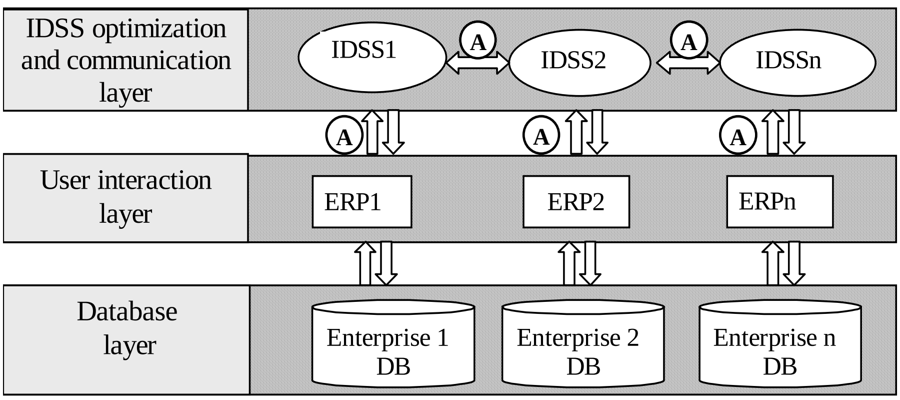

Figure 4. Multi-enterprise collaboration

To support a set of decision makers working together as a group, group IDSS have special technological requirements of hardware, software, people and procedures. Each member of the group usually has a personal computer, which is linked to the personal computers of other group members, and to one or more large public viewing screens, so that each member can see the inputs of other members or let other members see their work. Group IDSS software also need special functional capabilities, in addition to the capabilities of single user DSS software, such as anonymous input of the user's ideas, listing group members' ideas, voting and ranking decision alternatives. The people, as an important component of group DSS, should include a group facilitator, who leads the session by serving as the interface between the group and the computer systems [25].

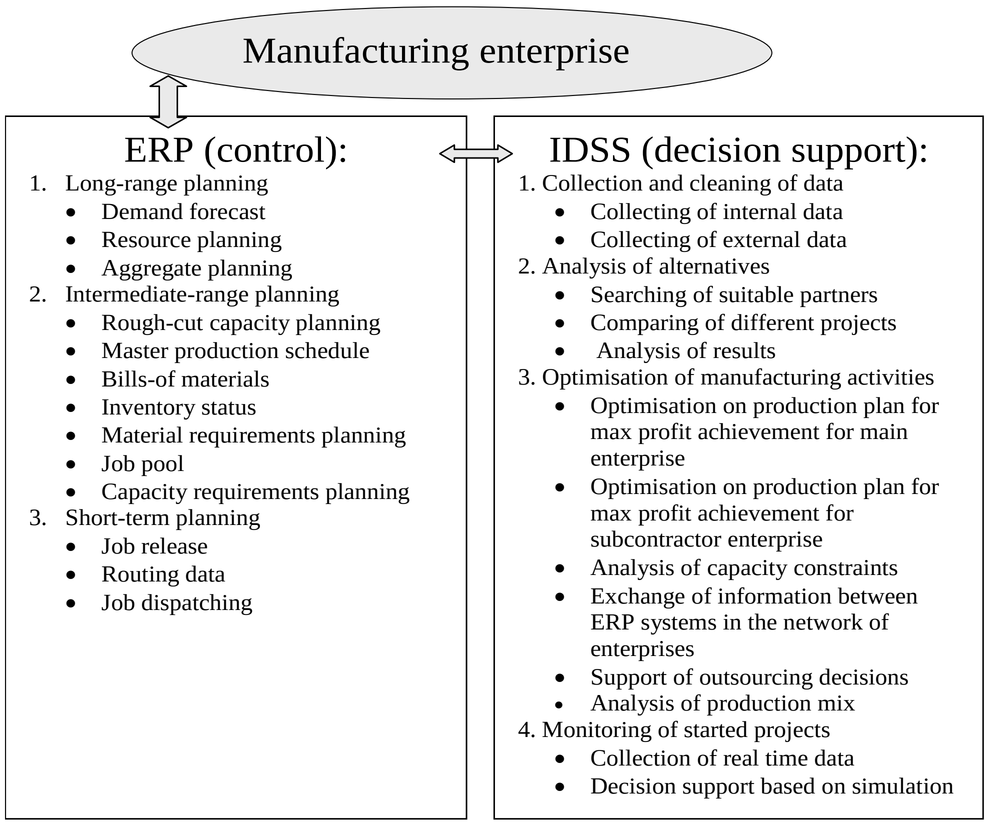

Figure 5. Tasks of ERP and IDSS systems are able to solve

The proposal of a Multi-Enterprise Collaborative ERP-IDSS conceptual framework allowed us to portray the existing range of quality solutions. These system framework proposals introduced a fresh perspective on the integration of ERP and IDSS, and their role in supporting firms in their quest to obtain and maintain valued relationships with their partners.

IDSS have the ability to take the integrated data stored within this database and transform it, through various analysis techniques. ERP systems are able to achieve integration by bringing together the data from different sources within the firm. This may include disparate databases that exist across different functional units, thus helping the firm to gain a more complete and realistic picture of all the data they hold. ERP systems have traditionally not been able to provide satisfactory support for transforming data, and enabling decision makers to discover and learn, ultimately turning this data into knowledge. This is where DSS have been able to give strong support [25].

It is possible to look deeper into the system in order to study the main functions performed by IDSS (see Figure 5). ERP packages are including standard functionality, and it is very costly to adapt system exactly to the requirements of the real enterprise. This is the reason that "vertical solutions" are developed. "Vertical solutions" are solutions build by third parties over the main functional ERP package that is developed for particular area of business. IDSS system vertical solution will enable to enhance the work of collaborative network of enterprises and helps to support business decisions making [V].

2.2.3 Conclusion of section 2.2

It is shown that ERP and DSS software are used for different purposes. Both applications are required for successful collaboration between enterprises. The DSS system can give new level of importance to the data extracted from ERP system and enhance management of decision support process. The IDSS system can be used to support the different kinds of decisions.

2.3 Methodologies selected for IDSS system

In this chapter methodologies that could be used by IDSS for decision support purposes are presented.

As World Wide Web is becoming an infrastructure of groupware applications, many companies apply groupware technologies to increase business-to-business collaborations among stakeholders in the supply chain over intranets and extranets. These include synchronous video conferencing, presentation, chatting, as well as asynchronous workflow management, document repository, wiki publication, etc .

The IDSS system is responsible for the management of information flows in the collaborative network of enterprises and enabling secure data transfers. The IDSS can enhance the effective usage of information available in the database of an ERP system. It also helps to archive and manage external information to make more reliable decisions. It is an intelligent system that can be trained towards the user's needs and preferences based on historical data [II].

The collaborative IDSS system consists of two parts. One collects and prepares the information, and the other is responsible for structured decision support. The structured decisions of IDSS are based on the parameters specified by a Management Company. The Management Company estimates the required resources for certain projects such as budget, time consumption, human resources, applicable technology and so forth. Non-structured decisions can be made in the way of modelling and analysis. A system interface will help the user to analyse the case, select appropriate tool for decision making in given situation, support in working with tools and collect the results. In a conglomerate company, information flows among children SME-s should be divided into the two main circles: internal and external. The IDSS system will enable the control over the information in both cycles.

The proposed information flow model is illustrated in Figure 6. Internal circle represents the internal environment of the concern including all SME-s (further *an internal enterprise*). In internal cycle, the IDSS uses the internal data resources for decision making process. IDSS is able to access different application on the same time and to use the latest available information directly, even before the reports for management will be produced. System enables user to use the different decision support tools for problem analysis. It will direct the user towards the decision making through interface dialog. System based on interaction with user will decide what the appropriate decision tool is and facilitate the work with the existing data [V]. For example, if the user is comparing different alternatives (products, projects, customers, subcontractors and etc.) on common base it is convenient to use AHP method [26, 27]. System will be able to provide the ranking of different alternatives. It will take into account that some parameters are more important than others are (the financial measures are more important than resource measurements). System is able to support user through the process of the optimisation of internal resources. It will be used for the improvements in production of highly ranked alternatives. The optimal planning solver can be used for this purpose [V]. The alternatives with low rankings should be investigated. It will be the source of additional resources, which can be used for the highly ranked alternatives or for the new alternatives.

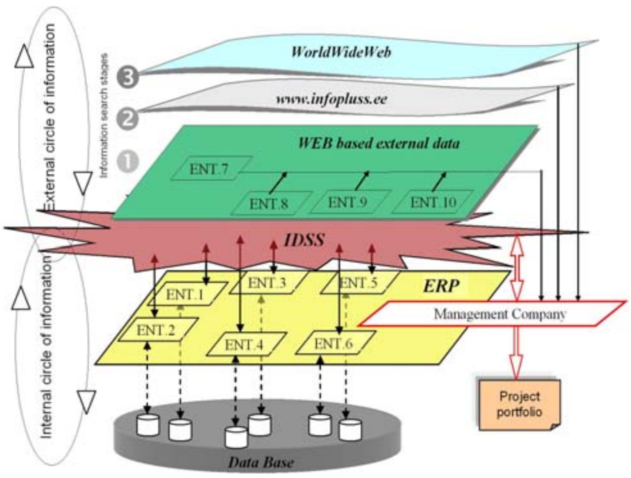

Figure 6. Information flow model in the collaborative network of enterprises

If the user is interested in investigation of new alternatives or in establishment of the collaboration with other enterprises, then the external cycle of information will be used. An external circle has three levels of information information about companies that SME-s are familiar to or have collaboration experiences with; information about new companies that are found from a national companies' database (for instance, *www.infopluss.ee* in Estonia); and information about totally unknown companies (domestic or abroad) with unknown technology, information from market research companies, etc. Information from the market research companies can be used for investigation of local and foreign markets. It could be used for the analysis of potential products or projects, which can be introduced on the market. If it is required to estimate how big could be the potential profit, how the situation will be changed if new competitor enters the market, or assess if the advertising company should be established we need to use appropriate analytical tool [XI]. For this purpose the decision tree can be used for the estimation of estimated profit [28].

After the product is selected and production is started IDSS will help to monitor the process flow and respond quickly to the user if the situation is changed. System will be able to see in advance if the situation is critical. For example if more resources were used, more materials were used or the competitors are introduced the similar products on the market the system will alert to the user that the probability of success was changed [II]. Bayesian network will be constructed for the appropriate monitoring of the processes. It is possible to construct model of the process, where all influencing factors are taken into account. If some parameter is changed the user will be able to see predicted change in success of final result. User is able to analyse situation in real time and estimate what could be changed in particular situation and how it will affect the final result [29].

This model development was based on practical experience achieved during collaboration with conglomerate shipbuilding enterprise. The new model enables to simplify the information collection process and improves the information quality and decrease the time required for this process. Also it supports the contact management process and improves the subcontractor selection process.

2.3.1 Data mining, data warehousing and information management

As shown in Figure 7, there are various components in a decision-making environment, including collection of data, storage of data, data analysis and knowledge discovery. The associated knowledge management activities include different analysis processes and process monitoring. Data from internal and external sources, spread across operational databases and data warehouses, are accessible by decision makers using tools for OLAP (On-Line Analytical Processing), data mining and queries. The decision makers gain new knowledge pertaining to the specific problem area through the experience of using such tools and techniques. The result of decision-making process itself is improved understanding of the problem and the process, and new knowledge generated. In other words, the decision-making and knowledge creation processes are interdependent. Proper integration of decision support and knowledge management will not only support the required interaction but also provide new opportunities for enhancing the quality of support provided by the system [30]. Specific decision support systems are usually based on the data extracted from various data sources and decision-making models extracted from various knowledge sources.

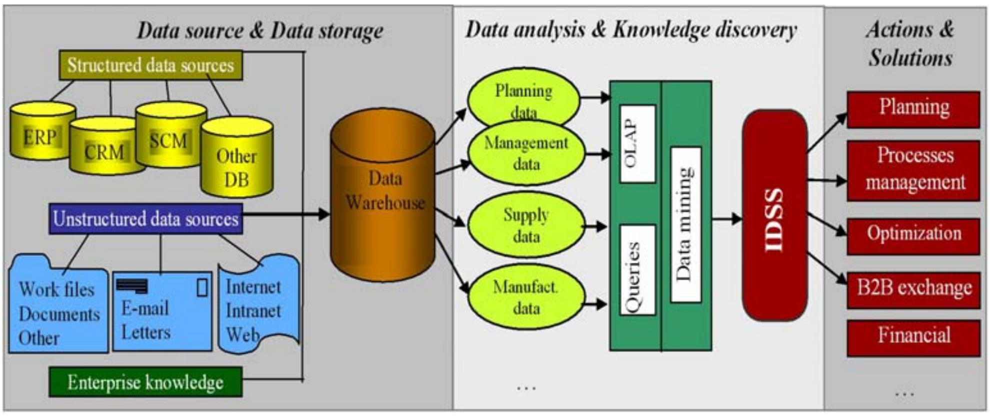

Figure 7. Decision support and knowledge management activities

2.3.2 Intelligent agents and interaction.

Negotiation is a decentralized decision-making process that seeks to find an agreement that will satisfy the requirements of two or more parties in the presence of limited common knowledge and conflicting preferences. Negotiation participants are agents who negotiate on their own behalf or represent the interests of their principals. When electronic negotiations enter the stage, these agents could be intelligent software entities that take part in the process of searching for an acceptable agreement. The degree of involvement of these “intelligence agents” in negotiations can range from supporting human negotiators (e.g. information search, offer evaluation) to fully automating the conduction of negotiations. Choosing the degree of agents’ involvement depends on the characteristics of the problem in the negotiation [20].

Negotiation is a decentralized decision-making process used to search for and leads to an agreement that satisfies the requirement of two or more parties in the presence of limited common knowledge and conflicting preferences. The Internet and new computing and communication technologies introduced new opportunities for the design and deployment of software capable of supporting negotiators, mediators and arbitrators. Negotiators conducted over the Web are commonly called e-negotiations and the systems used in e-negotiations are named e-Negotiation Systems (ENS-s.) Defining ENS-s as software deployed on the Web, capable of aiding one or more negotiators, mediators or facilitators allows us to include e-mail, chat and streaming video used in negotiations, as well as software used for automated negotiations and auctions. Specifically, the potential of intelligent software agents has been noted for their suitability in a distributed computing environment such as the Internet [20].

Software agents are programs that carry out certain operations on behalf of a user or another program with some degree of independence or autonomy and, in doing so, realize a set of goals or tasks for which they are designed. These programs differ from regular software because they are personalized, continuously running, and to certain extend autonomous. The reasoning mechanisms of software agents can range from a set of simple “if-then” rules to sophisticated machine learning algorithms such as neural networks or Bayesian networks [20].

The negotiation decision model comprises the following five phases:

The planning phase comprises activities that the negotiators undertake both individually and jointly. They formulate their representation of the negotiation problem including the specification of issues and options. If the negotiators know or can learn about their opponents, they decide on strategies to be used. This phase’s joints activity also includes the selection of the negotiation location and time, and the communication modes the negotiators will use.

Agenda setting and exploring the fields includes the negotiators’ discussions about the negotiated issues and their meaning. The discussion’s result may be new issues and options that are added or some may be deleted. The negotiators may also discuss the protocol they will follow, the timing of the exchanges, the deadline and – in some negotiations – their objectives, priorities and constraints. The result of these discussions is that the negotiators may have to revise the problem, objectives and preferences, and also their strategies and initial tactics.

Exchanging offers and arguments allows the parties to learn about the others’ limitations, and to identify the key issues and critical areas of disagreement. During this phase, the parties realize the potential of a compromise and can assess its main features. The analysis of a negotiation may focus on the modification of strategies, the determination of concessions and revision of aspiration levels, and on the restriction of efficient solutions to those that may be acceptable to the parties.

Reaching the agreement means that the parties realize that the negotiation has been successful. Having identified the critical issues, they may develop joint proposals or soften their individual limitations. The parties may also identify a limited number of possible compromises.

Concluding the negotiation takes place when the negotiators reach an agreement. They evaluated this compromise and considered its possible improvements. They also may discuss additional issues that, however, have no impact on the negotiations (e.g. the agreement implementation) [20].

e-Negotiation systems (ENS-s) have one or more of the following capabilities:

- To support decision and concession making;
- To suggest offers and agreements;
- To assess and criticize offers and counteroffers;
- To structure and organize the process;
- To provide information and expertise;

- To facilitate and organize communication;
- To aid in agreement preparation;
- To provide an access to negotiation knowledge; experts, mediators or facilitators.

NSS-s (Negotiation Support Systems) have very limited autonomy; their purpose is to provide support to one or more users to assess decision alternatives, select offers and evaluate counteroffers, and to communicate with their counterparts. In contrast, NSA-s (Negotiation Software Agents) have significant autonomy in their decision-making and communication activities. The NSA acts for and on behalf of the principal, the agent actively helps the principal and seeks information, evaluates the principal and other decisions, and communicates with the counterpart.

Agents possessing cooperation and autonomy features would be referred to as "collaborative agents", while those with learning and autonomy properties would be described as "interface agents". Agents possessing all three features were identified as "smart" agents. The types of agents that specifically suit e-negotiation tasks are described below:

User profile agent. The purpose of this type of agent is to elicit user preferences, and to assist the negotiator in deciding on objectives and strategies. Ideally agents of this type would be able to adapt to the changes in user behaviour in the process of negotiations.

Information agent. Agents of this type would engage in actively seeking, retrieving, filtering, and delivering information relevant to the issues on the table.

Opponent profiling agent. The primary purpose of this agent type would be to identify the objectives, preferences and strategies of the opponent. Knowing the opponent better renders offer generation evaluation and a much better informed decision-making process. The information and opponent profiling agent could be regarded as "intelligence" agents.

Proposer agent. The aim of this type of agent is to generate a set of promising offers to be considered for submission to the opponent. In negotiation problems that involve multiple issues, the generation of an offer may involve search in a very large space of possible offers.

Critic agent. The purpose of the critic is to evaluate the offers received from and addressed to the opponent and provide "verbal" feedback on the drawbacks and, possibly benefits of these offers. The proposer and critic agents could be regarded as a type of "adviser" agents.

Negotiator agent. This agent may be capable of conducting negotiations by itself in a semiautonomous or fully autonomous fashion. Applicability of full automation depends on the degree of certainty in objectives, preferences, and tactics of the negotiator (i.e. the level of structuredness of the negotiation task from the negotiator's perspective).

Mediator agent. The main purpose of this agent is to coordinate the activities of the negotiating parties, and to attempt to generate mutually beneficial offers. The role of this agent increases when the parties are willing to provide their information to a third party agent.

2.3.3 Optimisation of resource used

As the main model for the decision support the strategic (Aggregate) Planning (AP) is proposed [31]. A variety of manufacturing management decisions require information about what a plant will produce over the next planning period (planning horizon). The following information is included: staffing, procurement, subcontracting and marketing. The resources required to complete all manufacturing operations must be minimized; the gained profit must be maximized for the whole network. The goal is to implement long-term win-win relationship and information flow of all participating companies. Generally, the reasons of cooperation between the agents of network (subcontracting) are categorized into three main types:

Subcontracting of manufacture of raw material/parts/modules, semi-finished and finished products and components;

Technology driven subcontracting;

Capacity driven subcontracting.

When applied to the cooperative network of production enterprises the model of AP must outsource production quantities of all types of items in an optimal and appropriate way, from final products (end item) that are sold by product manufacturer, to components (lower-level items) that are used to build final product and produced by enterprise.

For each enterprise the following notations are introduced [32]:

i = An index of product, $i=1,....,m$, so m represents the total number of products;

j = An index of workstation, $j=1,.....,n$, so n represents to total number of workstations;

t = An index of time period, where $t=1,2,.....,tl$, where tl is the planning horizon for the problem;

$d_{it}^{\max}$ = Maximum demand for product i in period t;

$d_{it}^{\min}$ = Minimum sales allowed of product i in period t;

a_{ij} = Time required on workstation j to produce one unit of product i;

c_{jt} = Capacity of workstation j in period t in units consistent with those used to define a_{ij};

s_i = Selling price of product i;

r_i = Net profit from one unit of product i;

h_i = Cost to hold one unit of product i for one period t; for example, if holding cost consists entirely of interest on money tied up in inventory, then $h_i = i * C_i / 52$, where i is the annual interest rate and periods correspond to weeks. The holding cost for one period and associated with an average inventory is determined as $h*(I_{it} + X_{it} / 2)$;

C_i = Unit production cost (not accounting inventory costs) product *i;*

X_{it} = Quantity of product *i* produced during period *t* (assumed available to satisfy demand at end of period *t*);

S_{it} = Quantity of product *i* sold during period *t* (it is assumed that units produced in *t* are available for sale in *t* and thereafter);

I_{it} = Inventory of product *i* at the end of period *t* (after demand has been met); it is assumed I_{i0} is given as data;

The task is to find a function $F(X, S, I, D, C, I_0)$ that maximizes net profit minus inventory-carrying and holding costs subject to upper and lower bounds on sales and capacity constraints, where *X, S, I* are the vectors of decision variables and D ,*C,* I_0 represent the vectors of input data: demand, capacity and inventory at the begin of the planning period.

Linear program formulation of the task can be given $F(X, S, I, D, C, I_0)$:

$$\textbf{Max} \sum_{t=1}^{tl} \sum_{i=1}^{m} s_i * S_{it} - C_i * X_{it} - h_i * (I_{it} + X_{it} / 2) \qquad (1)$$

sales revenue-inventory and holding cost

subject to:

$d_{it}^{\min} \le S_{it} \le d_{it}^{\max}$ for all *i,t* demand

$\sum_{i=1}^{m} a_{ij} * X_{it} \le c_{jt}$ for all *j,t* capacity

$I_{it} = I_{it-1} + X_{it} - S_{it}$ for all *i,t* inventory balance $I_{it} \ge s_{it}$ for all *i*=1,*m,t*=0 requirements for safety stock

X_{it}, S_{it}, $I_{it} \ge 0$ for all *i,t.* non-negativity

Basic formulation contains capacity constraints for the workstations, but in some situations also other resources, such as people, raw materials, transport device capacity, allowed maximum for inventory (capacity of store(ware)houses), etc may be important determinants [32].

Generically,

b_{ij} = units of resource j required per unit of product *i*;

k_{jt} = number of units of resource j available in period *t*;

The general capacity constraints on resource *j* in period *t* can be expressed as (2):

$$\sum_{i=1}^{m} b_{ij} * X_{it} \le k_{jt} \tag{2}$$

The model helps agents to estimate the profit in particular conditions, which is useful for searching of optimum point to make win-win cooperation for all partners.

2.3.4 Comparison of alternatives

A methodology for the ranking of measures in a DSS has been developed in order to support policy makers to make a strategic selection between different measures while taking uncertainty into account. The methodology consists of an uncertainty analysis and a ranking procedure based on significance of the difference between output distributions [33].

Beliefs result from uncertainty. Uncertainty sometimes results from a random process (the objective probability case), it sometimes results only from the lack of information that induces some “belief” (“belief” must be contrasted to “knowledge” as what is believed can be false.) The uncertainty studied here concerns the one usually quantified by probability functions, as done by the Bayesians [34].

Any model that wants to represent quantified beliefs has, at least, two components: one, static, that describes your state of belief given the information available to you, and the other, dynamic that explains how to update your beliefs given new pieces of information become available to you. Unfortunately, too many publications are restricted to the static component and fail to detect the differences between the models based on belief functions [35].

Although decision making under uncertainty occurs in a variety of contexts, all problems have three common elements: (1) the set of decisions (or strategies) available to the decision maker, (2) the set of possible outcomes and the probabilities of these outcomes, and (3) a value model that prescribes monetary values for the various decision-outcome combinations. Once these elements are known, the decision maker can find an “optimal” decision, depending on the optimality criterion chosen [29].

However, once the decision is made, the outcome will eventually be revealed, and a corresponding payoff will be received. This payoff might be actually a cost, in which case it is indicated as a negative value. A payoff table lists the payoff for each decision-outcome pair. Positive values correspond to “rewards” (or “gains”) and negative values correspond to “costs” (or “losses”) [29].

There are different possible decision criteria. The maximum criterion finds the worst payoff in each row of the payoff table and chooses the decision corresponding to the maximum of these [29].

It should be noted that some authors differentiate between what they call “decision making under risk” (decision making when the state of the world is not known but probabilities for the various possible states are known) and “decision making under uncertainty" (decision making when the state of the world is not known and probabilities for the various possible states are not known) [35].

The Expected Monetary Value, or EMV, for any decision is a weighted average of the possible payoffs for this decision, weighted by the probabilities of the outcomes. Using the EMV criterion the decision with the largest EMV are chosen. This is sometimes called "playing the averages".

Some of the quantities in a decision analysis, particularly the probabilities, are often intelligent guesses at best. It is important, especially in real-world business problems, to accompany any decision analysis with a sensitivity analysis. Usually, the most important information from a sensitivity analysis is whether the optimal decision continues to be optimal as one or more inputs change.

Many decision problems are of this basic form, but many are more complex. A graphical tool called a decision tree has been developed to represent decision problems. They clearly show the sequence of events (decisions and outcomes), as well as probabilities and monetary values [29].

It is necessary to find the values of two types of information: sample information and perfect information. Sample information is the information from the experiment itself. Perfect information, is the information from the perfect test - that is, a test that will tell us with certainty which ultimate outcome will occur. The Expected Value of Sample Information, or EVSI, and the Expected Value of Perfect Information, or EVPI should be fount.

The EVSI is the most we would be willing to pay for the sample information.

EVSI = EMV with (free) sample information - EMV without information

EVPI = EMV with (free) perfect information – EMV without information

The information cannot be worth anything if it never leads to a different decision than we would have made without information.

In a contingency plan, later decision can depend on earlier decisions and information received. Most individuals are risk averse, which means intuitively that they are willing to sacrifice some EMV to avoid risky gambles. In terms of utility function, this means that every extra dollar of payoff is worth slightly less to the individual than the previous dollar, and every extra dollar of cost in considered slightly more costly (in terms of utility) than previous dollar. Even in the best of circumstances, when a trained consultant attempts to assess the utility function of a single person, the process requires the person to make a series of choices between the hypothetical alternatives involving uncertain outcomes. For these reasons classes of "ready-made" utility functions have been developed [29].

The AHP mechanism proposed by Saaty [22] is widely recognized as a useful tool to support multiattribute decision-making. The pairwise comparison ration, which is the comparison of the importance of criterion i and criterion j, that is w_i and w_j is defined as (3):

$$a_{ij} = w_i / w_j \tag{3}$$

Considering a pairwise comparison matrix $A = \lfloor a_{ij} \rfloor$ and the importance index (weight) vector $W = \lfloor w_i \rfloor$, their relationship can be described according to (4):

$$AW=nW \tag{4}$$

When A is given, W and n are calculated as an eigenvector and an eigenvalue of A, respectively. In this study, each agent has its own matrix A, and exchanges the matrix between agents to cooperatively adapt to changes in decision process. In AHP, the pairwise comparison matrix should be examined for reliability of consistency. The Consistency Index (CI) is calculated as (5):

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{5}$$

Where $\lambda_{\max}$ is the maximum value of 0. If the value of CI is higher than 0.1, the matrix should be reset by comparing importance again. Therefore the comparison matrix A should be focused on. Currently, most of researchers compose AHP comparison matrix A according to user's individual and flexible preferences. In a flexible negotiation environment, however, most of agents may change their offers according to counter offers [36].

2.3.5 Monitoring of established projects

In more complex problems, the number of outcomes could be larger, maybe considerably larger. It is then useful to represent the probability distribution of the monetary values for any decision graphically. The risk profile for a decision is a bar chart that represents the probability distribution of monetary outcomes for this decision [29].

In making a decision, it is desirable to utilize all available information. Thus, since Bayes´ rule provides a means of revising probabilities as new information is obtained, it is an extremely valuable tool in decision theory [36].

In multistage decision problems there are typically alternative sets of decision nodes and probability nodes. The decision maker makes a decision, some uncertain outcomes are observed, the decision maker makes another decision, more uncertain outcomes are observed, and so on. In a multistage decision tree, all probability branches at the right of the tree are conditional on outcomes that have occurred earlier, to their left. Therefore, the probabilities on these branches are of the form $P(A|B)$, read "A given B", where A is an event corresponding to a current probability branch, and B is an event that occurs before event A in time. However, it is sometimes more natural to assess conditional probabilities in the opposite order, that is, $P(B|A)$. Whenever this is the case, the Bayes' rule can be used to obtain the probabilities needed on the tree. Essentially, Bayes' rule is a mechanism for revising probabilities as new information becomes available [1].

To develop Bayes' rule, let A_1 through A_n be any outcomes. Without any further information the probabilities of the A's are $P(A_1)$ through $P(A_n)$. These are called prior probabilities. We then have the possibility of gaining some information. There are several information outcomes might be observed, a typical one of which is labelled B. It is assumed that the probabilities of B, given that any of the A's will occur, are known. These probabilities, labelled $P(B|A_1)$ through $P(B|A_n)$, are often called likelihoods. Because an information outcome might influence our thinking about the probabilities of the A's, we need to find the conditional probability $P(A_i|B)$ for each outcome A_i. This is called the posterior probability of A_i. This is where Bayes' rule enters the picture. It states that we can calculate posterior probabilities using the Bayes' rule (6):

$$P(A_i \mid B) = \frac{P(B \mid A_i)P(A_i)}{P(B \mid A_i)P(A_i) + \ldots + P(B \mid A_n)P(A_n)} \tag{6}$$

In other words, Bayes' rule says that the posterior is the likelihood times the prior, divided by a sum of likelihoods times the prior, divided by a sum of likelihoods times priors. As a side benefit, the denominator in Bayes' rule is also useful in multistage decision trees. It is the probability $P(B)$ of the information outcome or Denominator of Bayes' rule (7):

$$P(B) = P(B \mid A_i)P(A_i) + \ldots + P(B \mid A_n)P(A_n) \tag{7}$$

In the case where there is only two A's which we relabel as A and Not A, Bayes' rule takes the following form [29] (8):

$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B \mid A)P(A) + \ldots + P(B \mid NotA)P(NotA)} \tag{8}$$

We first decide whether to obtain some information that could be useful. If is decided not to obtain the information, we make a decision right away, based on prior probabilities. If we decide to obtain the information, then we first observe the information and then make the final decision, based on posterior probabilities.

Bayesian inference is possible to use for discrete and continuous probability models. Probability can be though of as a measure of uncertainty. At any given point in time, you may be uncertain about which of a number of events will occur. The information you have concerning the situation on hand can be represented by a set of probabilities for the possible events, and these probabilities can be used to help you make decisions. In many situations, it may be possible to obtain additional information before making a decision. What is needed is a method for combining the new information with the previously available information. The resulting decision or inferential statement can then be based on all available information. [36].

An important problem is the determination of the prior distribution and the likelihoods, two of the primary inputs to a formal Bayesian analysis. First, the decision maker must decide which uncertain quantities, or random variables, are of interest to him, and then he must express this information about these random variables in probabilistic form. Once all of the inputs are determined, the application of Bayes' rule is a simple arithmetic task. The prior probabilities should reflect the decision makes' prior information about the uncertain quantity in question. If this information is primarily in the form of sample results, then the prior probabilities should be close to the observed relative frequencies. When there are more than two possible events or more than two possible values of the uncertain quantity of interest, it is often convenient to determine a prior distribution by considering the relative chances of the various events or values of the uncertain quantity. It should be emphasized that whatever the technique or techniques used to assess the prior probabilities, the probabilities must be nonnegative and must sum to 1. If these requirements are not satisfied, then the probabilities are said to be inconsistent [36].

A Bayesian network is a type of graphical model those elements are nodes, arrows between nodes, and probability assignments. A finite set of nodes together with a set of arrows (directed links) between nodes forms a mathematical structure called a directed graph. Bayesian network can be considered as directed acyclic graph in which nodes represent random variables, where the random variable may be either discrete, with a finite set of mutually exclusive states which themselves can be categorical, discrete or continuous. Bayesian networks have a built-in computational architecture for computing the effect of evidence on the states of the variables. This architecture:

updates probabilities of the states of the variables, on learning new evidence;

utilises probabilistic independence relationships, both explicitly and implicitly represented in the graphical model, to make computation more efficient.

The human mind is good in selecting those features of reality that are important but poor at aggregating the features. Human experts are good in building the model, but they are not so good in reasoning through the model. A computer program is not good in building the model, but if is very good in performing calculations. It is acknowledged that Bayesian networks do not describe how the human mind works. It is claimed only that in simple cases, they provide intuitively reasonable answers, and that they are better than human minds in performing some more complex reasoning tasks. The goal in not to replace human experts, the goal is to help them [52].

The Bayesian network approach is used widely in different areas. It is widely used for the solving of medicine problems but it is also used for the solving of industry and production related problems. The interesting approach of on-line alert systems for production plants was proposed. This methodology was developed for detecting fault and abnormal behaviour in production plants. Proposed an alert system methodology based on conflict analysis. This methodology has been successfully tested on both real-world data from a power plant and simulated data from an oil production facility [37].

Bayesian network is successfully implemented for technology planning. The aim of the contribution was to design a technology planning system with flexible, adaptive planning logic with integrated data feedback of experience from the running-in process. It is possible to derive a "Bayesian belief network" structure for successfully planned products for which the planning data are stored completely oriented to processing elements. It is possible to update the network (the structure and the probabilities) and to expand, improve or optimize the decision base [38].

Bayesian belief network was also successfully applied to root cause diagnostics of process variations. Bayesian belief network methodology appears to be an effective tool for explicitly addressing uncertainty and utilizing data from multiple sources. After training on a data set of 16 trials, the network was able to correctly diagnose the correct state at a 60% confidence level in all but one of the 18 test cases [39].

The dynamic Bayesian network can be used as the knowledge base of the reasoning systems for the supply chain diagnostics and prediction, vendor appraisal, customer assessment, evaluation of strategic or technical alliance, and so on. The Dynamic Bayesian networks can be used to formulate the supply chain diagnostic problems and to show how the participating enterprises in the supply chain can solve the reasoning problems on the networks [40].

Efforts in decision theory may be divided into five categories [40]:

Decision making under certainty are those in which each alternative action results in one and only one outcome and where that outcome is sure to occur.

Decision making under probabilistic uncertainty are those in which one of several outcomes can result from a given action depending on the state of nature, and these states occur with known probabilities. There are outcome uncertainties, and the probabilities associated with these are known precisely.

Decision making under probabilistic imprecision are those in which one of several outcomes can result from a given action depending on the state of nature, and these states occur with unknown or imprecisely specified probabilities. There are outcome uncertainties, and the probabilities associated with the uncertain parameters which are not all known precisely.

Decision making under information imperfection are those in which one of several outcomes can result from a given action depending on the state of nature, and these states occur with imperfectly specified probabilities. There are outcome uncertainties, the probabilities associated with uncertain parameters, as well as imperfections in knowledge of the utility in various event outcomes.

Decision making under conflict and cooperation are those in which there is more than a single decision maker, and where the objectives and activities of one decision maker are not necessarily known to other decision makers. The objectives of the decision makers may also differ [40].

2.3.6 Conclusion of section 2.3

This chapter described the methodology selection process for IDSS for collaborative network of enterprises. The process should be started with information cleaning. Then it is required to manage the knowledge in the collaborative network of enterprises. The new framework for knowledge management in internal and external cycles of collaborative network of enterprises is proposed. The communication in the collaborative network of enterprises should be performed through agents, who are able to communicate with each other and exchange knowledge, required for decision making. Then it is important to find out which tools should be used to common decision making. We select linear programming for production plan optimisation. AHP is used for comparison of alternatives. It is also shown that Bayesian network is reliable tool for updating decision when additional information becomes available. Previously the Bayesian network wasn't used for the solving of the problems of collaborative network of enterprises but author think that it is suitable tool for process monitoring. It is also possible to predict how the situation will be changed if we select particular decision. The number of decision making tools is not final and it must be enlarged for the solving of new problems.

3 COMPUTATIONAL EXPERIMENTS

3.1 Decisions made under certainty

It should be stressed that decision making under certainty is not always as trivial as it seems to be. It may be solved by a technique known as linear programming. Other decision-making problems under certainty require the use of different types of mathematical optimization procedures. It should be realized that decision making under certainty includes many important and by no means mathematically trivial problems [36].

An intelligent decision support system may present information graphically and include an expert system or artificial intelligence. It may be aimed at business executives or some other group of knowledge workers.

A manufacturing decision support system is a strategic and tactical tool capable of supporting a variety of users in making informed decisions. The information from this system will be used to support the objectives of the corporation. With this objectives, it must allow users to analyse the past, manage the present, and investigate the future options [36].

3.1.1 Supporting of decisions in the collaborative network of SME-s

The IDSS accommodates data from several business functions. A diagram of production network management process is introduced in

Figure **8**. For description IDSS business functions IDEF0 method is used. The IDEF0 model reflects how system functions interrelate and operate; each side of a function box has a standard box/arrow relationship: input arrows interface with the left side of a box; control - with the topside; output - with the right side, and mechanism - with the bottom side of the box. Main benefit of IDEF0 model is that it may be transferred to the simulation model. The production network management process overview diagram ties together agents, data, external inputs and output, and shows the communication between activities.

For the analysis and production planning support it is important to have a combined network of production related information. The information will be collected from different enterprises in accordance with the cooperation agreement. For this reason, a computer network-centric multi-agent approach network is used [41].

A major characteristic of a decision support system is the inclusion of at least one model. The basic idea is to perform the DSS analysis on a model of reality rather than on the real system itself. A model is a simplified representation or abstraction of reality. It is usually simplified because reality is too complex to describe reality exactly and because much of the complexity is actually irrelevant in solving of the specific problem [42].

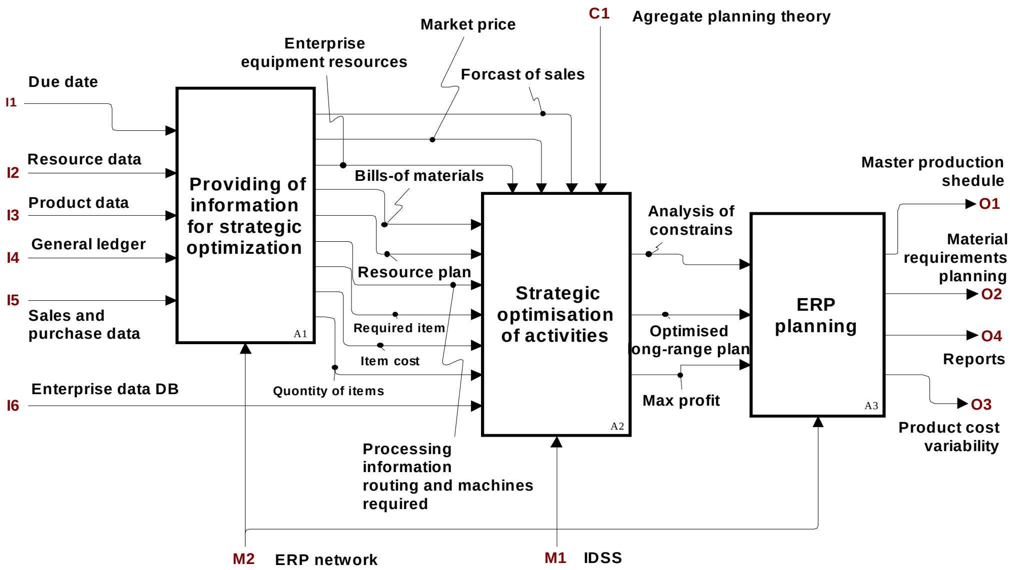

Figure 8. IDEF0 diagram of production network management process

3.1.2 Data warehouse prototype for the collaborative SME-s of Estonia

In the conditions of global competition, the enterprises require more and more information and it is not enough to use only local data sources. The enterprises are looking for the next level of data storages or data warehouses. If there is no required information in the local data warehouse, then enterprise will be able to search the required information from the next level or external data warehouses. The global data warehouse will be one logical database, composed from huge amount of physical data storages. Results at this phase are used to revise and develop the INNOCLUS database test version [VIII]. In a long perspective when a critical mass of companies are involved into the system results can support the strategic planning of technology transfer as well as it could be used as a basis for the industrial enterprises in order to elaborate co-operation networks and develop towards extended enterprises [43]. The data storage serve as central informational source for the collaborative enterprises inside community, where all required information could be requested. The rough information will be provided by data storage. The exact request will be sent in the form of quotation directly to the suitable production enterprise. Key element is the speed of required information collecting. In order to find required data quickly the Data Mining tools will be used. This tool will be able to search for required data in time effective manner, which increase the reliability of the solution [VIII].

3.1.3 Security issues in the network of collaborative enterprises

As we can imagine the security question is very important topic in the conditions of the real life. The mediator agent of different enterprises will be simultaneously looking for information required, but participants of collaborative enterprise network can be partners in one project and competitors in the next project. The question is how the participants could be sure that strategic information is secure? How the participant can prevent non-authorized access to strategically important data? Under such conditions, the data warehouse cannot have direct access to the databases of ERP systems of participants. Every contact must be authorized and only desired data must be transformed to the data warehouse. General information warehouse will achieve through import of the files with predefined structure, and further contact will be made already directly between potential partners. The data stored in the data warehouse will be confirmed by participants' agreements and updated periodically. This will eliminate the risk of not authorized usage of strategic information from databases of enterprise participants. Every user will have account protected by password. IDSS system will identify itself at the beginning of the session, and the connection will be automatically closed after the required information is downloaded [VIII].

3.1.4 Agents interaction

Multi-agent systems are distributed applications where single agents try to achieve co-ordination of their activities with other agents to create the intended overall system behaviour. Co-operation and co-ordinated behaviour of the agents depends on how single agents choose their course of actions. This decision process is based on the information, which is available to an agent [84].

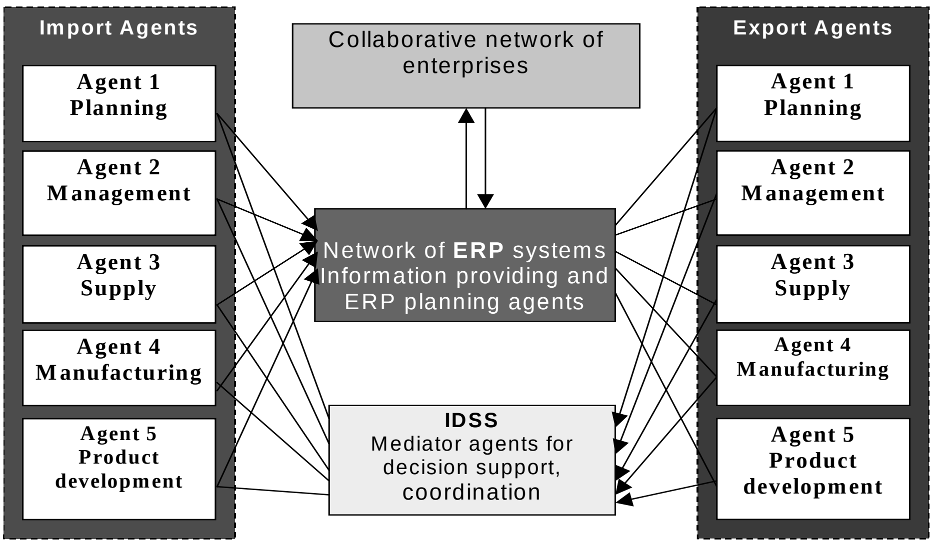

Figure 9. Computer network-centric multi-agent approach

The computer network-centric multi-agent approach is proposed to facilitate interactions between many agents participating in a product and manufacturing process development. It is proposed to use a decomposition scheme to disintegrate the initial task. The information is obtained from the collaborative network of enterprises, with or without ERP system and is represented in Figure 9.

The multi-agent system agents are used for data and knowledge import and export purposes. Each type includes agents for every activity of an enterprise, which must be sustained by the decision support system. If an enterprise has the ERP system then the intelligent decision support system exchanges information with the database of ERP system, if there are no ERP systems at an enterprise the information can be uploaded and downloaded through a web-portal of the intelligent decision support system. The data will be received and reworked by a mediator agent. The mediator agents have a complicated structure and are able to provide the decision support [VIII].

In Figure 10, a decision making scheme of information transfer is introduced. Each agent has a proper structure, which may be described by using several standards, for example the IDEF (Integrated Definition Language) or UML (Unified Modelling Language). The proposed models of agents should be adopted to a specific enterprise and enriched with specific information. Models information may be translated in the table form and used in other systems (for example in MS Excel) for further computing. Besides, it is possible to simulate the models and to obtain statistical results. The IDSS compares the derivable results by several parameters and can decide which enterprise can better solve the task.

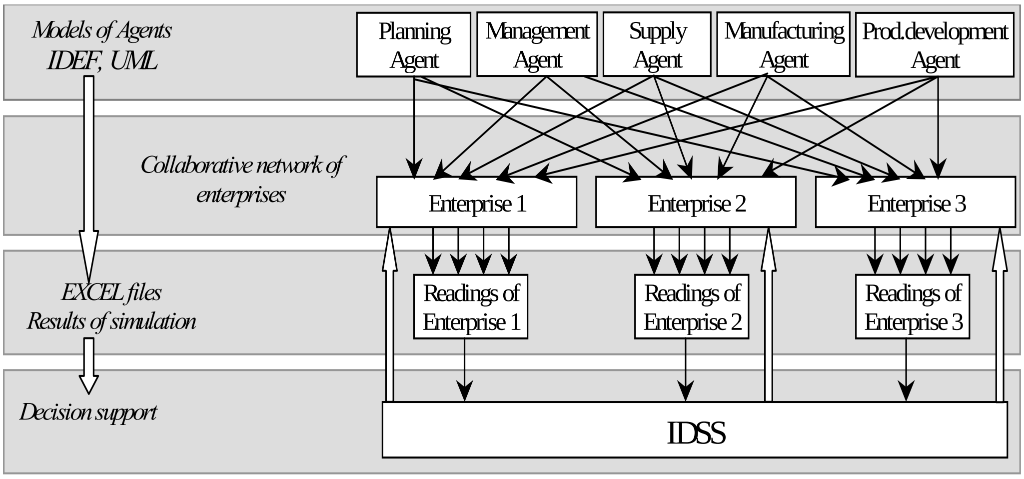

Figure 10. Decision making scheme by using agent approach

The application of multi-agent systems based on the concept of the distributed artificial intelligence is believed to be one of the most promising control architectures for next-generation manufacturing. Such systems are composed of distributed heterogeneous agents and make use of flexible control mechanisms for creating and coordinating a resulting society of agents [44]. This society of agents provides the foundation for creation of an architecture that possesses the capability to benefit manufacturing by enhancing a system's reliability, maintainability, flexibility, fault recovery, and stability, as well as providing means for real-time planning and scheduling.

An important aspect of agent technology is the ability of agents to co-operate in problem solving and to co-ordinate their activities to generate co-operation in an agent application. The co-operation is a concept of deliberative architectures, where the agents are able to maintain beliefs about other agents and where the agent's architectures provide communication facilities to enable a knowledge exchange between the agents.

The network-centric system consists of different agent types: information providing the agents, import, export and mediator agents. The structure of the mediator agents is the most complicated. In Figure 9, it is shown how the agents are communicating with each other.

The multi-agent approach to simulation modelling suggests an environment where agents can communicate and evolve. The properties of the agents and environments vary considerably depending on the modelling domain. On the other hand, such properties of agents as emergent behaviour and adaptation to environment through evolution are of general value in multiple domains. To realize these fundamental properties the core set of agent and environment features needs to be defined [45].

For the purpose of simulation, a collaborative network of enterprises is used, which consists of two enterprises: the main enterprise and subcontractor. It is the simplest case of production network and it is limitation for problem solving in this case. The main aim is to achieve the maximum profit, through the analysis and constrains elimination. The principle of collaboration between the agents will be described in order to understand the working principle. For simulation purposes the MS Excel worksheets are used, and for optimisation purposes the Solver tool of MS Excel is used [VI].

3.1.5 Optimisation of product flexibility

It is required to make decision related to the type of flexibility to be implemented by the manufacturing system in order to be able to manufacture all the parts within the product mix. Product, routing, expansion, and reconfiguration flexibilities are example of flexibility types [46].

The model for flexibility identification has been developed. This model is based on expert systems, specifically fuzzy systems, which determine which flexibility types (product, routing, expansion, and reconfiguration flexibility) are strategic for the enterprise, as the result of considerations on current products, potential products, business strategy, and competitive scenario.

There are also different scenarios for decision support. In the first case, some past information could be received for decision support (the case of the forecast). In another case, we have no analogous situation previously and we must be supported by different opinions of different experts. In some other cases, we can develop the model and simulate the situations in order to get decision support.

One common approach to deal with sets of scenarios is analyzing how the optimal solution would change with respect to different scenario; scenario analysis can be carried out by solving a set of optimisation models with alternative sets of data [47].

Uncertain inputs are another big problem. The sensitivity analysis approach is used to solve it.. In addition, the decision could be as accurate, as provided inputs enables. But it could be adjusted, when uncertainty is partly resolved due to some information added later. Also, the decisions could be partly made. In the beginning, the certain decisions are made, and uncertain decisions could be resolved later [47].

3.1.6 Single enterprise strategic production plan optimization agent

The user of the IDSS system is starting with the optimisation of a production plan operation for the product made on his own enterprise. The “Single enterprise strategic production plan optimisation agent” is started see Figure 11.

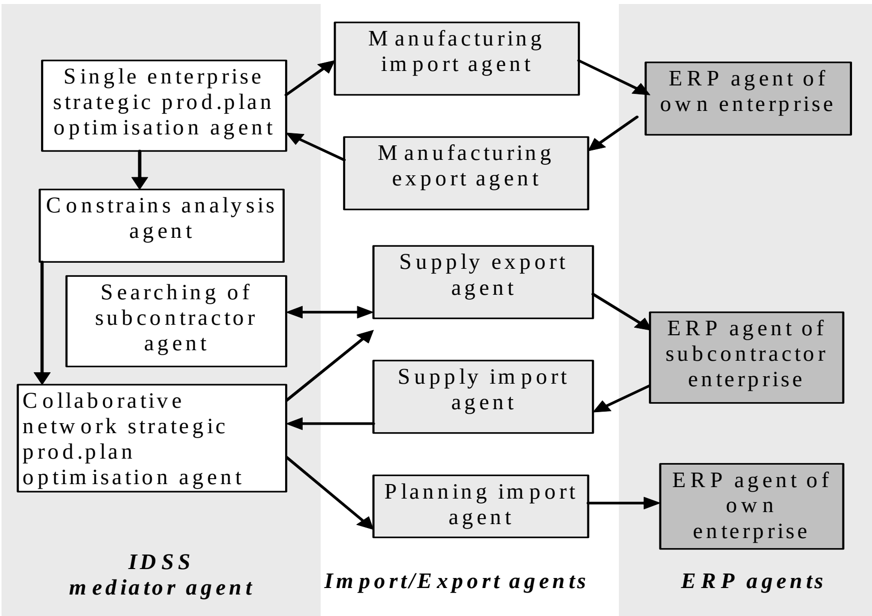

Figure 11. The scheme of communication between agents

The agent is communicating with an import agent in order to receive data required for optimisation from the ERP system of the enterprise (Figure 12). Product structure is described by the Bill of Materials (BOM) of the product (A5:A9). The production volume is calculated for the main product (C5:E5), and then the BOM is exploded and the requirements are calculated for all the parts (C6:E9). Also, the system receives the information about storage expenses (K11), salary per hour (K12), price of materials (K13), demand of the product (C18:E18), working centres capacity in hours (D21:F21).

The data for optimisation is transmitted to the "Single enterprise strategic production plan optimisation agent" and the optimisation process is started. Initially zeros for the decision variables were entered, but any other value can be set, which could be closer to an optimal solution than zeros. The problem of the finding optimal values for the decision variables is given over to the LP (Linear Programming) solver [VII].

	A	B	C	D	E	F	G	H	I	J	K	L
1	The whole product is made on one enterprise											
2												
3			Production volume									
4	Product structure		Period 1	Period2	Period3							
5	X_1=1	1	22	22	22							
6	X_2=4*X_1	4	88	88	88							
7	X_3=2*X_1	2	44	44	44							
8	X_4=2*X_2	8	176	176	176							
9	X_5=4*X_2	16	352	352	352							
10												
11	Price of produced unit		Profit per unit for X		155					Storage expenses	1	
12			Selling price for X		575					Salary per hour	25	
13			Raw material cost-X		310					Slig	10	
14			Unit (manuf) cost-X		110							
15			Total cost C_X1		420							
16												
17			d_X1	d_X2	d_X3							
18	Demand for product		40	40	40							
19												
20				WS_A	WS_B	WS_C						
21	Working centers capacity in hours			2400	3000	2400						
22												
23			Time required on WC to produce one unit of product									
24				WS_A	WS_B	WS_C						
25			Item 1	12	0	0						
26			Item 2	16	4	0						
27			Item 3	0	10	0						
28			Item 4	2	0	1						
29			Item 5	0	6	2						
30												
31												
32												
33	Variables			Period 1			Period 2			Period 3		
34		IX_0		X_11	S_X1	I_X1	X_21	S_X2	I_X2	X_31	S_X3	I_X3
35	Product X_1	0		22	12	10	22	22	10	22	22	10
36	Product X_2			88	0	0	88	0	0	88	0	0
37	Product X_3			44	0	0	44	0	0	44	0	0
38	Product X_4			176	0	0	176	0	0	176	0	0
39	Product X_5			352	0	0	352	0	0	352	0	0
40	E12*E35-E15*D35-K11*B35-D35/2*K11+E12*H35-E15*G35-K11*F35-G35*K11/2+E12*K35-E15*J35-K11*I35-J35*K11/2-K11*L35											
41	Objective	Max profit										
42			4417,00									

Figure 12. Data required for production plan optimisation

Once the decision variables are specified, an objective function to find the maximum profit in cell (C42) could be constructed, the formula is inserted into the cell (C42) and can be read in the cell (A40 in Figure 12). Next, it is required to specify constraints. To do this, it is necessary to develop formulas that compute the left-hand side of each constraint. For clarity reasons the formulas from E column are copied to D column (Figure 13). Constrains (B46:B57) are defined by the BOM structure. The constrains (A58:A60) mean that the safety stock of the second period minus the safety stock of the first period, minus the items produced plus the sold items equals to zero. Constrains in the cells (A61:A69) are constrains of the working centres, constrains in the cells (A70:A72) are the sales constrains of the market, and constrains in the cells (A73:A75) represent the safety stock constrains. There is no need to do the same with the nonnegative constraints since it is a simple matter to choose all the decision variables and force them to be greater than or equal to zero in the Excel Solver menu. When a solution is generated, it could be interpreted by an answer report. Answer report also gives more details on the constraints by showing ones are binding or tight (or equal to the right hand side (E row is equal to G row). In the example after the Solver was started the maximum profit achieved for a single enterprise was 4417 EUR (cell C:42 in Figure 12).

	A	B	C	D	E	F	G
44	**Constraints**						
45							
46	Period1	X_2=4*X_1		D36-4*D35	0	=	0
47		X_3=2*X_1		D37-2*D35	0	=	0
48	Period2	X_2=4*X_1		G36-4*G35	0	=	0
49		X_3=2*X_1		G37-2*G35	0	=	0
50	Period 3	X_2=4*X_1		J36-4*J35	0	=	0
51		X_3=2*X_1		J37-2*J35	0	=	0
52	Period1	X_4=2*X_2		D38-2*D36	0	=	0
53		x_5=4*X_2		D39-4*D36	0	=	0
54	Period2	X_4=2*X_2		G38-2*G36	0	=	0
55		x_5=4*X_2		G39-4*G36	0	=	0
56	Period 3	X_4=2*X_2		J38-2*J36	0	=	0
57		x_5=4*X_2		J39-4*J36	0	=	0
58	I_X1-IX0-X_11+S_X1=0			F35-B35-D35+E35	0	=	0
59	I_X2-I_X1-X_21+S_X2=0			I35-F35-G35+H35	0	=	0
60	I_X3-I_X2-X_31+S_X3=0			L35-I35-J35+K35	0	=	0
61	Work center A loading at first period			D25*D35+D26*D36	0	<=	2400
62	Work center B loading at first period			E25*D35+E26*D36-	0	<=	3000
63	Work center C loading at first period			F25*D35+F27*D36-	0	<=	2400
64	Work center A loading at second period			D25*D35+D26*D36	0	<=	2400
65	Work center B loading at second period			E25*G35+E26*G36-	0	<=	3000
66	Work center C loading at second period			F25*G35+F26*G36-	0	<=	2400
67	Work center A loading at third period			D25*D35+D26*D36	0	<=	2400
68	Work center B loading at third period			E25*J35+E26*J36+I	0	<=	3000
69	Work center C loading at third period			F25*J35+F26*J36+I	0	<=	2400
70	Sales constrains at first period			E35	0	<=	40
71	Sales constrains at second period			H35	0	<=	40
72	Sales constrains at third period			K35	0	<=	40
73	Safety stock for I_X1			F35	0	>=	10
74	Safety stock for I_X2			I35	0	>=	10
75	Safety stock for I_X3			L35	0	>=	10

Figure 13. Constraints of the single enterprise

When a solution is generated the next agent “Constrains analysis agent” will be started. It is based on the answer report of the solver answer. The agent is checking all constrains of the solution and finding out the binding constraint. The system will compare the existing values with the limits (Figure 14).

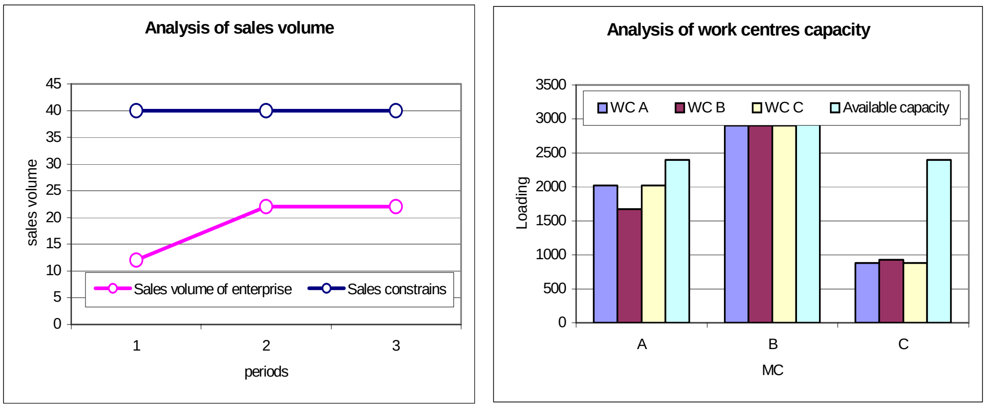

Figure 14. Analysis of limits

After the analysis, the system will propose us to use collaborative network outsourcing possibilities in order to maximise the profit achieved.

3.1.7 Collaborative network strategic production plan optimization agent

If a user accepts the proposal, the next agent "Collaborative network strategic production plan optimisation agent" will be started automatically. The agent will use the data from the previous agents. In our case, after analysis it will propose to outsource the product X_2 to the sub supplier in our collaborative network. It enables to exclude the work centre C (WC_C) from the production process, and the loading bottleneck at the work centre B (WC_B) in (Figure 14). The agent will generate an optimised production plan and propose the quantity of subcontracted items. The agent will communicate with the supply export agent in order to receive the exact cost of subcontracted items from the ERP system of the subcontractor [VII].

3.1.8 Searching for a subcontractor agent

In case if item was not ordered previously the "Searching of subcontractor agent" will be started. The searching for the subcontractor agent is an independent unit, which is aimed at searching for suitable subcontractors for performing outsourcing activities. The process of a subcontractor selection is developed by the IDEF0 methodology (see Figure 15). The process starts when a task for the outsourcing requirements from constrains analysis agent is received. The received parameters must be satisfied. The agent will search for the requirements, which satisfy the subcontractors from the external DB of a group of production enterprises, which contains product, production and contact data of participant enterprises. The search is performed by the following criteria's: the type of a required item (I1), the cost of the item (I2) and the quantity of the item (I3). All the subcontractors, which satisfy the searching parameters, will be selected and transformed to the internal database of the IDSS system. Only those subcontractors, which have required quality certificate, will be selected. Then the "Searching of subcontractor agent" will send quotations with the subcontracting requirements. If the proposal is suitable for the subcontractors they will reply to this e-mail. The reply must include the conditions of delivery, quality data and information about the price and quantity filled in a standard form, which will be included in the e-mail attachment. When all information about subcontracting conditions is transformed to the IDSS system, it will be able to perform the profit analysis with all suitable subcontractors and select the most suitable ones.

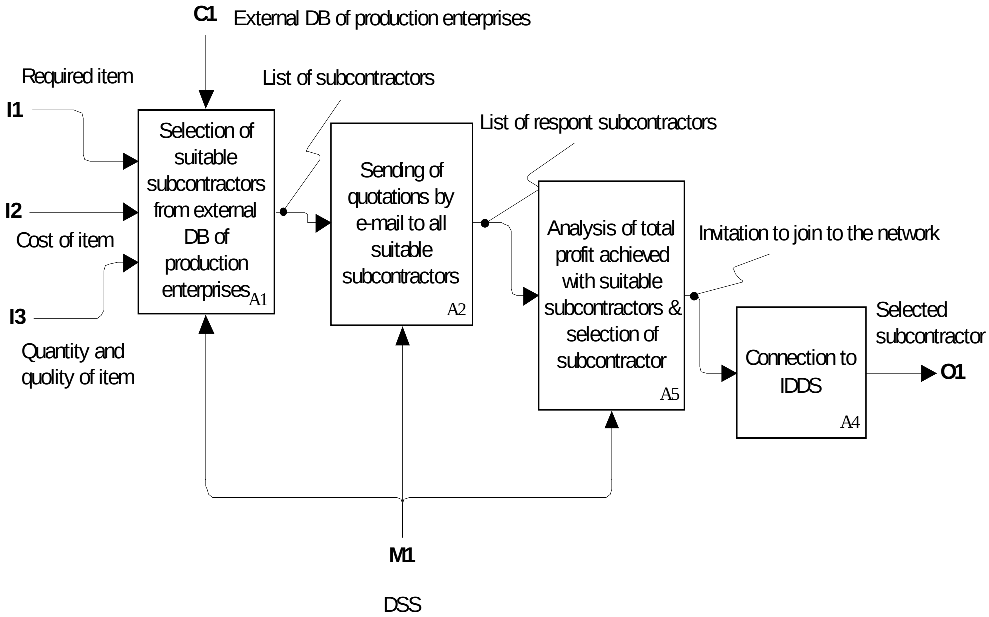

Figure 15. Process of the subcontractor selection

The analysis based on the data received from subcontractor includes the quantity of the required items, due date and total prices (sales price and delivery expenses). The output of the analysis is a simulated profit figure for every subcontractor. When the most profitable subcontractor is selected, the IDSS system will send an invitation to the selected subcontractor to join the network. The invitation will include the instruction how to connect to collaborative network of enterprises and achieve the collaboration agreement about possible data transfers. After the collaboration agreement is accepted the subcontractor can be connected with the IDSS network. In the real life, the price conclusion is an important part of every contract, but the IDDS system is also able to help the participants to find out the optimal product price for both sides. It could be seen from the graph there does exists the optimal point when both sides will receive the max profit (Figure 16). In our case the proposed subcontracted price is 358.7, and the profit achieved by the main and the subcontractor enterprise is ~13136.

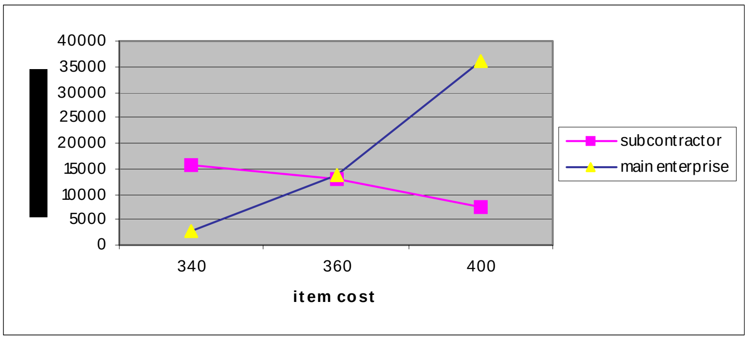

Figure 16. Dependability of profit of subcontractor and main enterprise

Then the mediator agent will be able to analyse new constrains. For this purpose, the system uses the analysis report of the solver. Every constraint is given the Lagrange Multiplier. The Lagrange Multipliers have an economic interpretation of marginal values (shadow prices) of resources. In our case the Lagrange multiplier shows that main constrains are products X_2 and the sales volume for all periods; this is the key to the further process of profit maximization. Then the optimised strategic plan will be send to the ERP system by the “Planning import agent” (see Figure 11). After that, the intermediate and short term planning will be performed by the ERP systems of the participants, which is performed by the ERP agent of an enterprise [VII].

3.1.9 Conclusion of section 3.1

In this chapter was described how IDSS will be able to support decision making that enables profit maximization in the boarder’s frames of collaboration network. System enables:

The max profit optimisation in the conditions of existing constrains;

The decision support for outsourcing;

The supporting of information flow between ERP, MRP II and MRP and intelligent system;

Minimizations of collaboration problems through decision-making support.

In this computational experiment the max profit achieved after the Solver was started for single enterprise was 4417 EUR. After the establishment of collaboration we can see that main enterprise profit will be increased up to 13136 EUR and the same profit will be received by the subcontractor enterprise.

3.2 Comparison of alternatives for strategic decision making

In this part is shown how the AHP and decision-making theories are used for comparison of alternatives. It is required to compare different products and strategies for strategic decision making. IDSS enables to compare different products based on different criterions and select the best alternative for presentation of new product on the market. Case study is presented to illustrate how the IDSS supports strategic decisions making.

3.2.1 Case Study of strategic decision making for collaborative enterprises

For practical experiment of strategic decision-making the network of collaborative enterprises is considered. It includes manufacturing enterprise, its vendors, customers and subcontractors. Also, the information provided by marketing and market research companies is required. The business decision-making process is very costly process. The food production enterprise “Meat&House” uses the great amount of data for decision-making process support. This practical experiment describes the original concept of knowledge management phase of knowledge preparation for decision-making process. At the moment the enterprise hold the 90% of local food processing market share. The enterprise produces about 200 different products. The lifecycle of every product should be held under control all the time. The original concept of the company is to make the tastiest product with reasonable price for the local market. Questionnaires and surveys are used for market research purpose. It is quite difficult process, because 95% of the products are sold to the several wholesalers. The company uses own brands and also others brands for the products. Sales forecast is used to estimate how many products will be sold in the next period. The most profitable are the frozen foods family products, which can be grouped as: Pelmenis, Varenix, Quenelles, Pancakes, and Forcemeat. Due to big variety of products, it is difficult to make the precise analysis. Aim of the analysis is to avoid production of non-profitable products. It requires improvement of the manufacturing process continuously. The production lines with the high productivity should be purchased and installed continuously. The use of best practice is also important process. Benchmarking is used to compare the company with the other Europe leaders in food sector. Also, it required to launch the new products, which are predicted to have good sales at near future. Decision making of what products should be launched next in such situations is a profit related process and must be supported by IDSS system. The IDSS will provide the knowledge management process followed by data optimisation. Work will be started from required data selection, data processing and data transforming to data warehouse. Required data should be requested from different data sources, then processed and structured before a data mining process.

3.2.2 Knowledge Management and decision support based on Internal Data

Some data could be received from some already structured data sources such as enterprise ERP systems. The following data are of the particular interest: unit production cost, overheads per unit, selling prices, annual sales per year, etc. For computational experiment four different products were ranked. The ranking should be made based on the available data. It is inconvenient to evaluate different product data and specify the priorities. The common rule should be used. For this purpose, the Analytic Hierarchy Process will be used see Table 4. Data for the weight calculation includes available products needed to be compared (this data is received from the ERP system of the enterprise).

Scoring method is a popular technique for evaluating large-scale technical projects, such as the choice of a telecommunications package, especially when there are multiply proposals with varying prices and capabilities [47]. Scoring techniques focus on a list of desired performance characteristics. Weights are assigned to them and each alternative is rated. In our case for evaluation of alternatives the software "Super Decision" is used. There are different requirements and their units of measurement are also different. To get the score it is required to look for the smallest value in every line and divide all values in the line by this value. The result will be that the smallest value will have weighted as one, and weights of the others will be bigger. The weights are given in brackets in Table 4. These weights are used in Super Decision Model (SDM). A SDM consists of clusters of elements (or nodes). In our case the clusters contain the same type data elements see Figure 17 [XI].

Table 4. Data for the weight calculation

Product USD/100kg / Requirements	Chinese Pelmenis	Favourite Quenelles	Berry Varenix	Delicious Pancakes
Profit USD/1000kg (weight points)	1570 (1,4)	1160 (1)	1830 (1,6)	1510 (1,3)
Annual Sales volume in tones (weight points)	1200 (4,8)	350 (1,4)	500 (2)	250 (1)
Machine resource requirements h/1000kg(weight points)	2,8 (2)	1,4 (1)	2 (1,4)	4 (2,9)
Production Labour req. h/1000kg (weight points)	24 (2,4)	41(4,1)	21 (2,1)	10 (1)
Production area req. m2/annual.pr. (weight points)	800/1200 (1,1)	400/350 (1,9)	300/500 (1)	300/250 (2)
Fridge and storage cost per USD/1000kg (weight points)	270 (1,08)	250 (1)	270 (1,08)	300 (1,2)
Loss from production process % (weight points)	2% (1)	4% (2)	2% (1)	4% (2)

The other important factor that must be considered is that some requirements are more important than others are. Decision Support software enables to set up relationships between requirements.

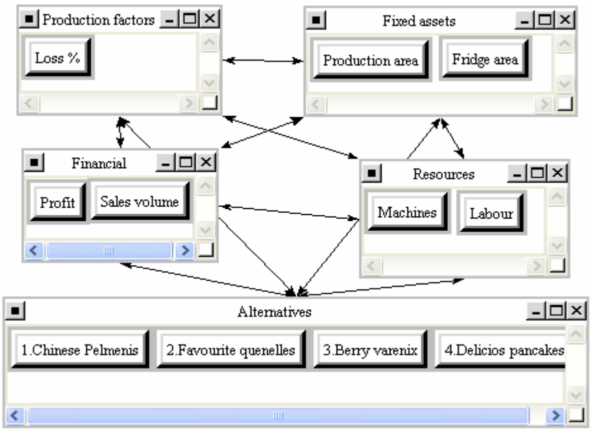

Figure 17. Super decisions model for decision-making

In this experiment (Figure 18) it is assumed that financial cluster is of highest importance and other clusters are given the lower priorities for decision support.

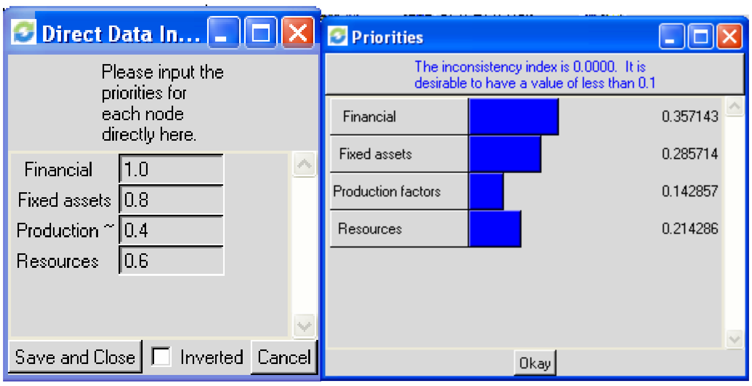

Figure 18. Cluster priorities for decision support

The result of our analysis includes the ranked products (Figure 19). Ranking of products enables general comparison of the different products and selection the most profitable ones. Those products are the profit making or money-spinner products of the enterprise in the present period. In our case, those products are Chinese Pelmenis and Pancakes. Manufacturing process of those products should be optimized, in order to increase the profit and to minimize the usage of the resources. Also, it is useful to analyse in case if some processes could be successfully subcontracted. For this purpose, the IDSS will use the Solver tool. The production plan will be optimised and system can propose, which processes and product parts should be subcontracted. The products that have low ranking points are less profitable and could be replaced by the new products. Still some of those products can be used as loss leaders for attraction of new customers or as the new market entrance products.

Graphic	Alternatives	Total	Normal	Ideal	Ranking
	1.Chinese Pelmenis	0.0584	0.2710	1.0000	1
	2.Favourite quenelles	0.0516	0.2395	0.8836	3
	3.Berry varenix	0.0511	0.2371	0.8751	4
	4.Delicios pancakes	0.0544	0.2524	0.9314	2

Figure 19. Alternative ranking of analysed products

3.2.3 Knowledge Management and decision support based on External Data

The process of data request from external sources is more complicated and time consuming process. An intelligent decision support system may present the information graphically and include an expert system or artificial intelligence. It may be aimed at business executives or some other group of knowledge workers. All partners share the responsibility for reaching the defined target. The conditions for collaboration are satisfied, when two or more companies co-ordinate their aims, expectations and resources distribution in the process of cooperation, based on harmonious collaboration culture [1]. After the estimation of the results of Internal Data analysis, it is required to find out if more profit could be made. First of all, it is planned to come to the new market with the new product "meat pancakes". This product is directed to the younger generation. The idea is to make new brand, which will attract the people who have no time for food preparation and do not like sweet food. The research data related to new market is received. The sales forecast for new market is about 500 tones of new product per year.

Now it is necessary to estimate what will be the new products price, and what influence it will make on profit received. For this purpose, the Palisade decision tools software is used. The input data is could be seen in the Table 5.

Table 5. Input Data for Price Selection decision Support

Inputs	**Thousand USD**
Investment to enter new market	$60
Production costs	$1 166
Probability that competitor will not come out with similar product	0,3
Estimation if the price is concurrent	**Price related probability**
<$1250K	0,2
$1250K to $1350K	0,4
$1350K to $1600K	0,3
>1600	0,1

The following data is known: the investment cost for coming into new market, the annual production cost, and the price related probabilities.

Now the decision tree is constructed, which will help to select decision (Figure 20).

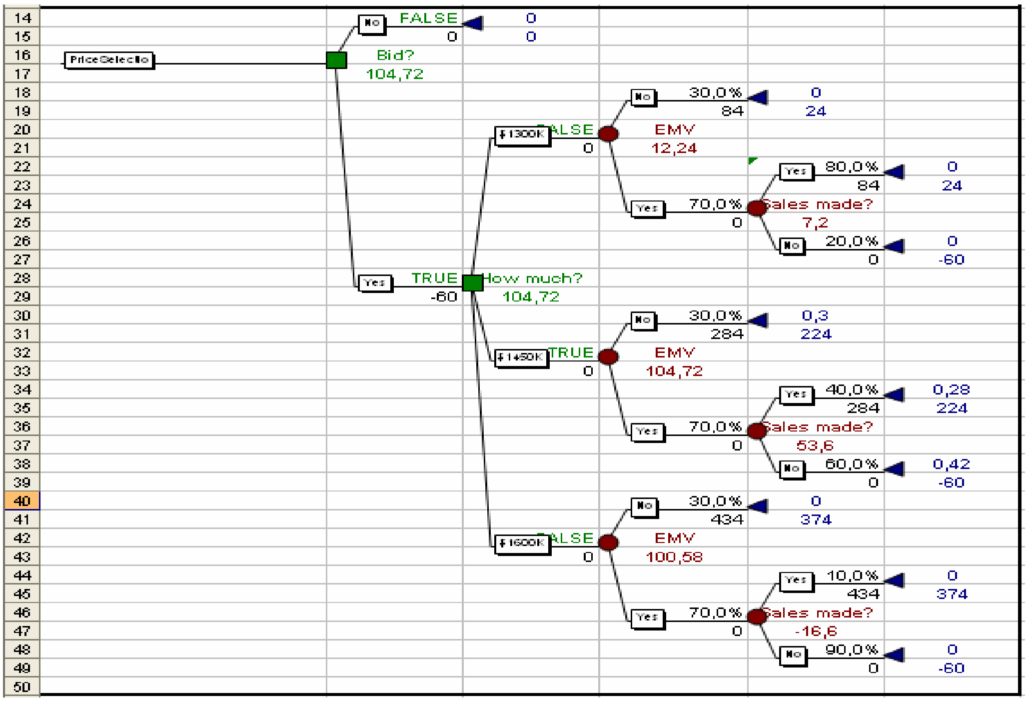

Figure 20. Price selection decision support

The expected monetary value approach is used. The Expected Monetary Value for any decision is a weighted average of the possible payoffs for this decision, weighted by the probabilities of the outcomes. Using the EMV criterion, the decision with the largest EMV is chosen.

Now it is decided to enter to the new market, but there are no enough resources. As for the main model for the decision support, a strategic (aggregate) planning is proposed. The resources required to complete all manufacturing operations must be minimized; the gained profit must be maximized for the whole network of enterprises. The goal is to implement a long-term win-win relationship with information flow of all the participating companies. Now it is decided to outsource the part of our “Pelmenis” product branch, but it is required to find a suitable subcontractor and the IDSS must help to perform it. The data received from external sources should be transformed to common format. The data is processed and transformed to a data warehouse. The data is shown in Table 6.

Table 6. The structured external source data

ID	Enterprise name	An industry	Sector	Product groups	Products
1	Elcot	Manufacturing	Food	Frozen meat,	Pelmens, Varenix, Quenelles, Pancakes and Forcemeat
2	Profiles&Steel	Manufacturing	Steal	Sheet metal	U.profile, Z profile
3	Myhouse	Manufacturing	Wood	Furniture	Tables, chairs, beds
4	Greep	Manufacturing	Food	Bread	white bred, black bred
5	Screen	Manufacturing	Electronics	TV, DVD	DVD players, TV sets, radios
6	Almat	Service	insurance	House insurance	Full home insurance package, basic package
7	Rums	Service	computer software	ERP	Scala, SAP, Axapta
8	Relmax	Service	computer software	CAD	Acad, SolidAge
9	Recel	Manufacturing	Food	Frozen meat,	Pelmenis, Varenix, Quenelles, Pancakes
...	Dix	Manufacturing	Food	Fish	Pelmenis
n	Glastex	Manufacturing	Building	Doors, windows	Wooden doors

The cleaned information "List of potential customers" can be stored to the data warehouse. In the beginning, the system will filter the data related to manufacturing enterprises, then the food sector data will be selected and in the end, the data related to frozen products will be received. This process was simulated. Five replications were made in Arena simulation software and the system selected 32 subcontractors. This list of potential subcontractors can be used by data mining process. The IDSS will send a request by email to potential subcontractors. Replies will be analysed. The suitable combination of: the required operation; suitable cost, required volume and flexibility constrains of the subcontractor enterprise should be found. Simulation of the process is shown in Figure 21. The selected subcontractor's information is stored in the data warehouse and will be used for subcontracting. The system will also send an automatic reply to the non-selected subcontractors. It is always important to have a look in the near future. It is required to analyse the current market situation, to understand future trends and predict what will be the market taste in the near future and what potential products should be prepared for the changed market situation. The data received from marketing companies should be analysed. It is required to estimate product suitability for an enterprise; as well as the resource requirements. The resources that will be free after eliminating the non-profitable products could be used for the production of small quantities of new products. Then it will be possible to make a test launch of the product and to estimate the potential success of the new product. The result of the knowledge management process is reliable knowledge that is used for a decision-making process in the network of collaborative enterprises [XI].

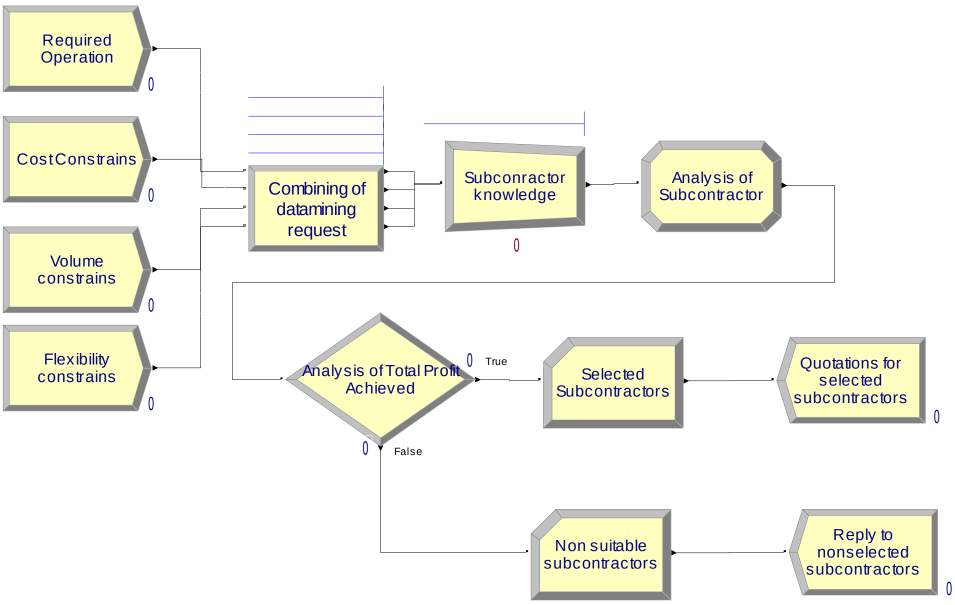

Figure 21. Selection of suitable subcontractors from the list of potential subcontractors

3.2.4 Conclusion of section 3.2

The chapter describes a case study process of knowledge discovery and decision support process. This process prepares knowledge that could be used by the IDSS system for decision support purposes. The proposed solution brings together benefits of the available technologies of data querying, warehousing, analysis and visualization, as well as information retrieval and sharing knowledge with its users. It is shown how it is possible to rank different alternatives by the use of Analytical Hierarchical Process. Then the method of decision tree is used for the management decisions support. The process of subcontractor selection is simulated. The following software is used for this paper: Super Decisions, Palicade Decisions tools, and Arena simulation software. The aim is to show that the IDSS system is an important part of a collaborative network of SME enterprises, which will be able to make fast analysis of the tasks. It is especially important in the conditions of the frequent changes in the market situation.

3.3. IDSS system for different projects alternatives comparison

This chapter presents how IDSS can be used for decision making related with comparison of different projects. The AHP and project management theory are used for this purpose.

3.3.1 Decision support in project management field

Projects exist in every type of enterprise. They are unique, complex undertakings that create new products, facilities, services, and events. Projects have starting and ending points in time and progress through a number of life cycle phases.

Projects are comprised of diverse tasks that require diverse specialist skills, and hence cut across the traditional functional organizational lines. The challenge is to accomplish the right projects at the right time

The projects managed by the enterprise have different purposes and extent. The projects usually are: project of building a new workshop or its modernization; project of purchasing and installing new equipment; project of reorganization of the current equipment stock with the purpose of increasing the performance and etc. They could be determined by time of implementation, budget, or a number of persons involved [48].

3.3.2 Portfolio selection

Project portfolio selection (Figure 22) is the periodic activity involved in selecting a portfolio of projects, that meets an organization’s stated objectives without exceeding available resources or violating other constraints [49].

Choosing the right projects to invest in can make the difference between corporate survival and failure. Some of the issues that have to be addressed in this problem are the organization’s objectives and priorities, financial benefits, intangible benefits, availability of resources, and risk level of the project portfolio.

Many methodologies have been developed for dealing with this problem, including techniques which evaluate individual projects or which select a portfolio from among available projects. Also, there exist some process frameworks for project portfolio selection which is adaptable to the needs and preferences of the corporation, and which provides an approach for selecting a portfolio that meets the organization’s requirements.

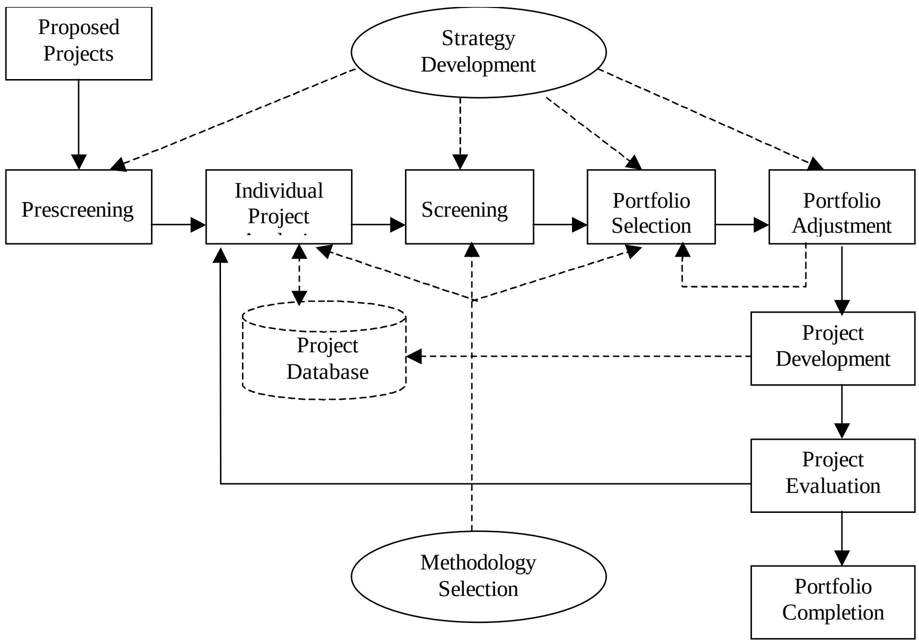

Figure 22. Project portfolio selection

The following methodology application enables the project manager to evaluate whatever project's contribution into enterprise [49].

3.3.3 Realization in decision support software

Establishing the priorities of the projects IDSS will be able to take into account all importance aspects and will propose logical solution. For this case study the program “Super Decisions” is used. This program is based on ANP (Analytic Network Process). ANP is the most comprehensive framework for the analysis of societal, governmental and corporate decisions that is available today to the decision-maker. It allows one to include all the factors and criteria, tangible and intangible that has bearing on making a best decision. The Analytic Network Process allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such feedback best captures the complex effects of interplay in human society, especially when risk and uncertainty are involved. The ANP, developed by Thomas L. Saaty [21], provides a way to input judgments and measurements to derive ratio scale priorities for the distribution of influence among the factors and groups of factors in the decision.

Typical ANP-based projects have concerned: prioritizing alternatives and resource planning, including product, project, and job selection; employee evaluation system; facility location; vendor selection; and transport mode or carrier selection [50].

Ratio scales make possible proportionate allocation of resources according to derived priorities (see Figure 23).

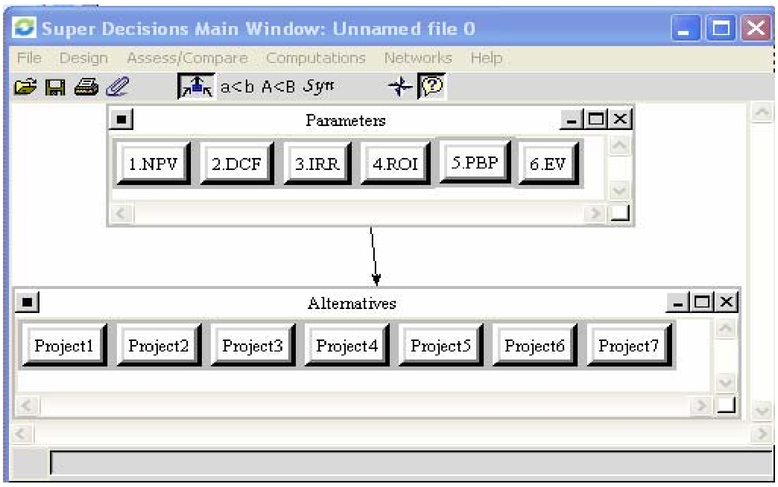

Figure 23. Analytical Network Process

The ANP program is able to calculate the priorities for all projects. IDSS takes into account parameters: Net Profit Value (NPV), Discounted Cash Flow (DCF), Internal Rate of Return (IRR), Return on Original Investment (ROI), Return on Average Investment (RAI), PayBack Period (PBP), and Expected Value (EV). At the beginning two clusters are designed: parameters and alternatives. Parameters cluster includes nodes, which are related with parameters of interest and cluster of alternatives includes nodes of different projects.

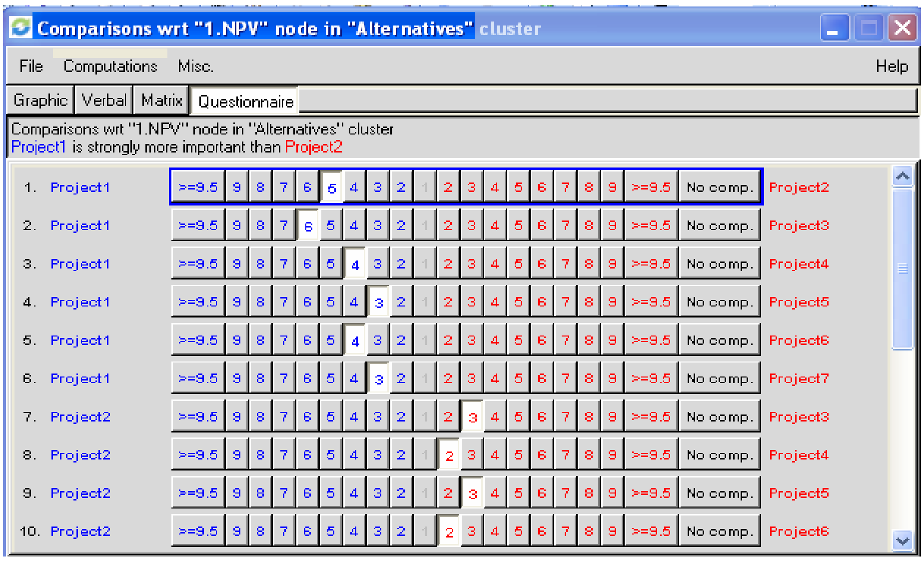

Figure 24. Comparative matrix

For assessment, required data is imported from ERP system of internal enterprises. The parameters for different projects are compared to each other. The working principle is simple. The first parameter assessed is NPV. In the first line the NPV of Project 1 is compared to NPV of Project 2 (Figure 24). In given case study the NPV of Project 1 is 5 times higher than for Project 2.

The same comparison is made for all projects. Now it is required to estimate what priorities have every project in relation to NPV. When all data is inserted it is required to check if all the comparisons are logical. The system is able to check the data inconsistency.

Then the next parameters are inserted and assessed in the same way. When the total data is valid system is able synthesize the priorities of the projects. In our case study the priorities by the projects are: 4, 1, 2, 3, 5, 7, 6. The project portfolio is composed.

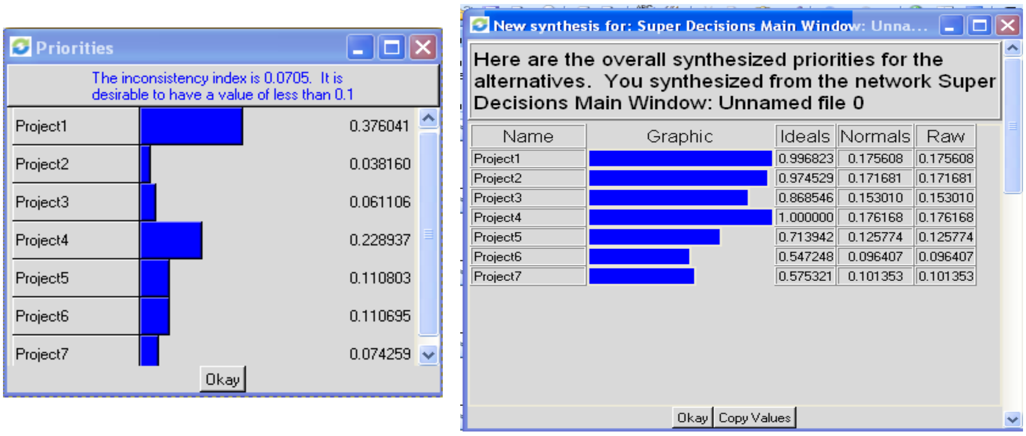

Figure 25. Project portfolio selection

3.3.4 Conclusion of section 3.3

The solution for Intelligent decision system presented in this chapter will support the work of different ERP systems of enterprises as one network, which will give big advantages to participating enterprises. It differs from previous proposed by its optimization ability and decision support for optimal project portfolio selection, security features and adjustability to particular requirements of collaborative enterprises. Potential customers are collaborative SME-s, which are interested in the optimization of commonly used processes.

3.4 Collaborative decision making for manufacturing project management

In this chapter presented how IDSS is able to support decision making for probability success monitoring in collaborative network of enterprises. The Bayesian methodology is used for this purpose.

Today's competitive marketplace requires that enterprises should be more flexible, innovative and responsive to their customers' needs. Therefore, it poses challenges to small and medium sized enterprises (SME-s) so that their traditional business models should be changed and new ones to facilitate collaboration with suppliers and customers need to be adopted. Next-generation enterprises will form complex collaboration networks in supply chains, which value information sharing in order to reach their respective goals of time, cost, and quality. The availability of information enables the management team to make right decisions at the right time to react responsively according to the individual objectives (e.g. customize a product, provide special services, outsourcing) [66].

3.4.1 Decision theory for manufacturing projects decision support

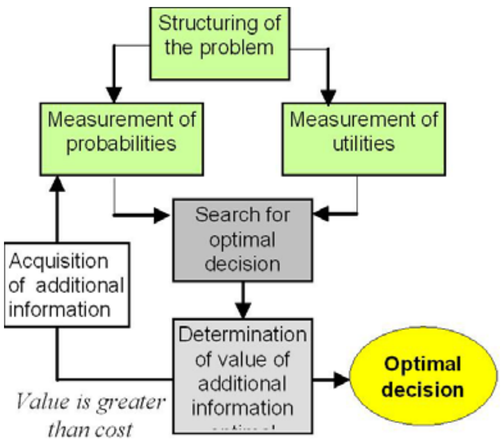

Figure 26. Searching for optimal decision

In previous chapters, it was demonstrated how the IDSS could be used for the optimization of engineering and production planning for collaborative SME-s [VI]. In this chapter, the IDSS is applied to manufacturing projects. A knowledge management framework and information flow management by IDSS are introduced. A case study for analysis of real-life manufacturing projects is demonstrated.

The BBN approach is used for decision making. The decision maker is concerned with determining the likelihood that a hypothesis (H_i) is true. Bayesian interface is the technique for interfering the probability (P_i) that a hypothesis (C) is true, from evidence (E_j) linking the hypothesis to other observed states of the world. The approach makes use of Bayes' rule to combine the various sources of evidence. The Bayes' rule states that the posterior probability of hypothesis H_i given that evidence E_j is present, or $P(H_i|E_j)$, is given by the equation (9):

$$P(H_i \mid E_j) = \frac{P(E_j \mid H_i)P(H_i)}{P(E_j)} \tag{9}$$

where P(Hi) is the probability of the hypothesis being true prior to obtaining the evidence Ej, and P(E |Hi) is the probability of obtaining the evidence Ej given that the hypothesis Hi is true. Eq. (9) predicts the probability that that the projects will be successful if the information is achieved:

P(project is successful)= P(project is successful|information is available)P(information in general)

+P(project is successful|no information is available)P(no information in general))

When the evidence Ej consists of multiple states E1, E2,…, En, each of which is conditionally independent, the Bayes' rule can be expanded into the expression:

$$P(H_i \mid E_j) = \frac{\prod_{j=1}^{n} P(E_j \mid H_i)P(H_i)}{P(E_j)} \tag{10}$$

A Bayesian network contains three elements: nodes, arrows between nodes, and probability assignments. A finite set of nodes together with a set of arrows (directed links) between nodes forms a mathematical structure called a directed graph. The Bayesian network can be considered as a directed acyclic graph in which nodes represent random variables, where the random variables are usually discrete with a finite set of mutually exclusive states which themselves can be categorical, discrete or continuous. The computational architecture of Bayesian networks computes the effect of evidence on the states of the variables. The architecture:

updates probabilities of the states of the variables, on learning new evidence;

utilises probabilistic independence relationships, both explicitly and implicitly represented in the graphical model, to make computation more efficient.

3.4.2 Analysis framework for manufacturing orders supported by IDSS

Management of manufacturing projects can be widely applied in creation of new products, facilities, services, and events, in organizational changes and restructure, or recovery from natural or man-made errors. Projects have starting and ending points in time and progress through a number of life cycle phases. In this case study is given the illustration of how IDSS system is able to support selection and planning of manufacturing projects. IDSS system will help to gather required information, then it will help to analysis information received and estimate if selected projects will be successful. After manufacturing projects are started it will be possible to monitor the present situation and respond quickly if new information is received [III].

Step 1 - Collection of the required information.

The collection of the required information about quoted manufacturing projects from daughter companies (see Figure 27).

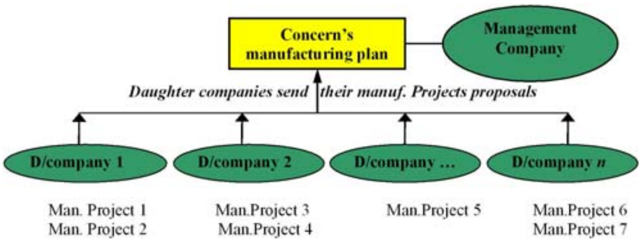

Figure 27. Collection of quoted manufacturing projects

Daughter companies (subsidiaries) propose quoted manufacturing projects for future period. Since every company has its own distinctive development strategy, therefore a number of projects and their attributes are different as well. All this information (project description, feasibility study, etc.) is delivered from companies to the managing company that is engaged in verification, agreement, and further deployment of these projects [III].

Step 2 - Project description.

This process requires a significant number of resources and knowledge of the project structure [52]. At the moment all collaboration is performed manually. IDSS must be able to support this process. Common format for all internal enterprises is developed and should be filled automatically by IDSS (Figure 28) [III].

Project: ***Forge workshop modernizing***			
NN	Parameters/ criterions (planned):		
1	*Start*	15-Jan-07	
2	*Finish*	16-Aug-07	
3	*Budget*	$ 1.500.000	
4	*Goal*	Revenue growth	
5	*Net profit value*		
6	*Internal rate of return*		
7	*Volume*	20000 year	
8	*Cost of equipment*	$ 400.000	
9	Risk of the manuf.proj.	....	

Figure 28. Fragment of a project describing file

The input of process will be collection of internal enterprise common files. Output will be the whole concern consolidated file. This file will be used for further step.

Step 3 - Preliminary planning of single projects.

At this stage all projects should be planned in detail. Firstly it is necessary to estimate all the projects on the base of corresponding criterions [53, 54]. IDSS will use common project template, which includes tasks and steps: designing; manufacturing; installation; inspection. It is possible to include as much tasks and steps as necessary (see Figure 29).

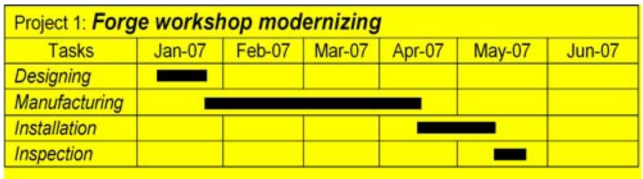

Figure 29. Gantt chart for a certain project life-cycle

Step 4 - Timetables of manufacturing projects.

IDSS will include the calendar of all manufacturing projects in a consolidated fashion. Here users can see and compare all projects on the same screen (see Figure 30).

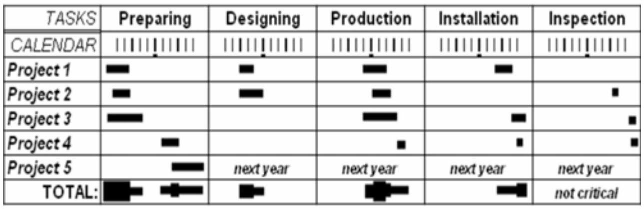

Figure 30. Project calendar within the year

Step 5 - Establishing the priorities.

The IDSS takes into account all important aspects, and users can propose some logical solutions based on the result of data analysis. This process is based on AHP or Bayes' rule. The AHP will be used if there is no exact information about future manufacturing projects. The Bayes' rule can be used when there is enough information to select the most profitable or the less risky projects [55].

Step 6 - Optimisation of manufacturing project calendar.

If some resources are overloaded, the IDSS system will propose to re-plan resource usage backward. The projects with lower priorities will be postponed. It is possible to make this operation manually. It is also possible to track the solution methodology if required and will optimize the collaborative work.

Step 7. Estimation of success of selected manufacturing projects.

During the project start-up stage the Bayesian network was constructed. Bayesian networks create a very efficient language for building models of domains with inherent uncertainty. Fortunately, software tools which can do the calculation job for us are available [56].

For this research the Microsoft Belief Networks (BSBNx) software is used. For estimation of success of manufacturing projects, the Bayesian network was constructed based on prior probabilities. This is what is known about projects, market situation and company information before the project is started. It is known that success of our manufacturing projects depends on such factors as: stable product price; stable product cost; availability of resources; stability of our subcontractors and stability of our market share (see Figure 31). Then it could be seen that availability of resources depends on availability of labour and availability of machine resources. Stable product cost related with the stability of components costs and the stability of the labour cost. Component prices depend on such parameters as: increase of material prices on the market; increase of transport cost and increase of handling cost (see Figure 32).

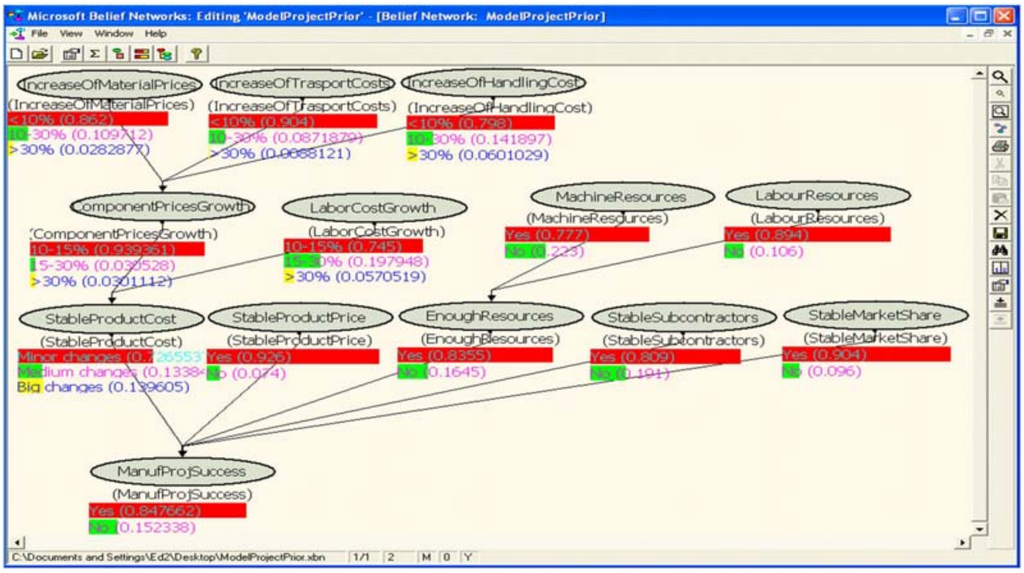

Figure 31. Bayesian network for estimation of Manufacturing projects success

Assessment (Model: ModelProjectLast3, Node: ComponentPrices)

Parent Node(s)			ComponentPrices			
IncreaseOfMaterialPrices	IncreaseOfTrasportCosts	IncreaseOfHandlingCost	10-15%	15-30%	30% and Up	bar charts
<10%	<10%	<10%	1,0	0,0	0,0	
		10-30%	0,95	0,05	0,0	
		>30%	0,9	0,05	0,05	
	10-30%	<10%	0,95	0,05	0,0	
		10-30%	0,9	0,05	0,05	
		>30%	0,85	0,08	0,07	
	>30%	<10%	0,9	0,05	0,05	
		10-30%	0,85	0,08	0,07	
		>30%	0,8	0,1	0,1	
10%-30%	<10%	<10%	0,85	0,1	0,05	
		10-30%	0,8	0,12	0,08	
		>30%	0,883	0,09803	0,01897	
	10-30%	<10%	0,8	0,12	0,08	
		10-30%	0,75	0,15	0,1	
		>30%	0,7	0,2	0,1	
	>30%	<10%	0,7	0,2	0,1	
		10-30%	0,65	0,25	0,1	
		>30%	0,6	0,28	0,12	
>30%	<10%	<10%	0,05	0,25	0,7	
		10-30%	0,02	0,23	0,75	
		>30%	0,015	0,235	0,8	
	10-30%	<10%	0,02	0,18	0,8	
		10-30%	0,08	0,12	0,85	
		>30%	0,03	0,12	0,85	
	>30%	<10%	0,01	0,04	0,9	
		10-30%	0,005	0,045	0,95	
		>30%	0,0	0,0	1,0	

Figure 32. Assessment of nodes relations

Step 8. Monitoring of projects based on Bayesian network.

Small change in situation can affect the on-time completion of non-profitable manufacturing project. IDSS support system must be able to respond quickly to changes. Today efficient report systems are used, but still it takes time to analyze the reports. And it is common situation that required information is received too late and enterprises faced with the fact that profit is lower than it was planned.

Here the IDSS will be able to respond quickly to changed situation. It is possible to use IDSS system analytical mechanism to respond to the information received in real time. It is only required to show to IDSS system the resources, where information could be searched for. The Bayesian network is able to support decision making for corrective actions. In this case the additional information achieved in relation to the manufacturing project in process.

The information that the transportation cost on the market is increased for 30% and the salary of our labour was increased for 31% is received. Now it is important to assess how it will affect our project's success. System is able to make real time analysis of project success based on new information (Figure 33). The information received will be new posterior probability from the Bayesian network. In this way, the system will hold under control our manufacturing projects and it is possible to establish deep analysis of system sensitivity to different inputs changes. The user is just need to respond to this knowledge. In such situation could be estimated what parameters are possible to improve and to estimate how it will be reflected on projects success. It is possible to try to buy more machines to decrease the number of working stuff. And may be it is required to join some partners to combine the transportation cost. The efficient tool can be used, which is able to receive the answer to what if situation in dynamic way, and it is possible to make much more effective decisions [III].

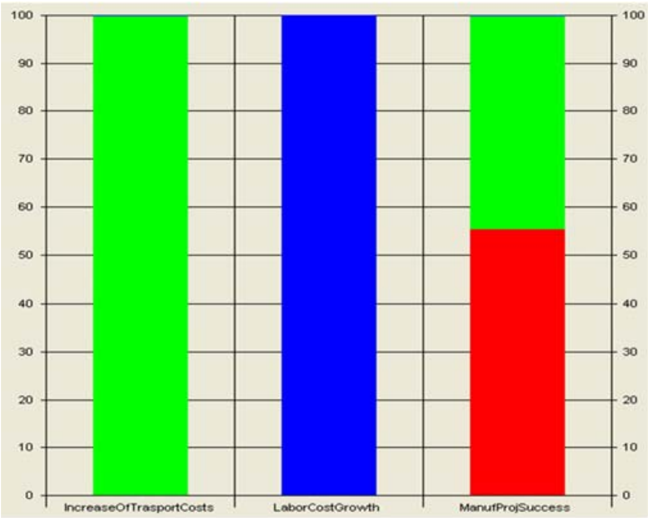

Figure 33. The evaluation of manufacturing project success based on the last information received

3.4.3 Conclusion of section 3.4

There are several advantages to use IDSS for manufacturing project selection and management. In this case study, several benefits are presented, including the increased number of alternatives examined; fast response to unexpected situations; improved communication; control; cost savings; scale savings; better decisions; more effective team work; time savings; making better use of data resource; integrated risk assessment; logical selection of manufacturing projects.

Bayesian network can help to transform information into knowledge. Integrated approach saves time for company management. IDSS enables the tracking of decision-making process, which enables users to study and to better understand the made decision. Now it is possible to see how the latest information reflects on our projects and how it is possible to perform more effective decision. It is possible to simulate and assess in which directions the work must be made. This chapter gives new knowledge about the framework how the IDSS and ERP systems can be used together to collect information, clean and analyze it, assess and track manufacturing projects.

3.5 Decision Support process in the field of Reverse Logistics

In this chapter will be introduced how IDSS system can support reverse logistics decisions. The need of reverse logistics management is becoming imperative as many companies are not prepared for the reverse flows of products. Traditionally, industries focus on the forward supply chain management, which is the delivery of products from manufacturer to the marketplace. However, the attention to reverse logistics recently increases since the total value of products returned in the U.S. is estimated at $100 billion annually [56].

Reverse logistics is the logistics process of returning new or used products from their initial point in a supply chain such as returns from consumers, retailers or distributors for the reason of unsatisfactory products, outdated products, overstocked inventory or recalled materials. The Council of Logistics Management (CLM) published the first known definition of reverse logistics in the early 1990s as [57]: "the role of logistics in recycling, waste disposal, and management of hazardous materials; a broader perspective includes all relating to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal". The driving force for reverse logistics has been classified into economics, legislation and extended responsibilities. Reverse logistics consists of planning, implementing and controlling the reverse flow of materials and management of related downstream information through the supply chain with the primary purpose of recapturing value. Thus, the associated decisions may drive a large extent of development in the process of manufacturing and remanufacturing, forward and backward material flows, and related operational functions.

Reverse logistics is characterized by some highly uncertain factors, such as the quantity of reverse material flows, the quality and a wide variety of return products, the timing of returns, the potential residual values, and the demand of the secondary market. Therefore, it requires a robust Intelligent Decision Support System to select the proper recovery channels and activities to be applied on the returned product. An IDSS is a strategic and tactical tool capable of supporting a variety of users in making informed decisions. Information from this system will be used to support both the external and the internal objectives of the corporation. The effectiveness of an IDSS is dependent on the alignment of two conditions: the ability to collect the required data from the business functions and the conversion of the data into useful information. One of the challenges for decision making in reverse logistics management is the lack of information and knowledge (e.g., under which working environment products were used by customers, how they were maintained, what the long-term impact on environment and energy consumption will be) such that risks associated with environment, health, reusability, total cost of ownership, etc. should be considered.

The objective of this chapter is to provide a reliable IDSS framework under uncertainties to maximize the net product lifecycle asset value recovered from the flow of returned products. It is proposed to consider a range of situations, instead of one situation, during decision-making. The intervals are used for representation of uncertainties and to consider all possibilities of variations in worst cases, in combination with probabilities that address variabilities. Robust Bayesian networks are applied to compute imprecise posterior probabilities to increase the robustness of IDSS. Thus, uncertainties associated with probabilistic distributions are considered in the probabilistic reasoning, which are inherent in stochastic models especially when the sample size of input analysis data is small and available evidences are not enough.

Chapters 3.5.1 and 3.5.2 gives a brief overview of types of research in reverse logistics, intelligent decision support and imprecise probability. Chapter 3.5.3 describes a general framework of closed-loop supply chain in our reverse logistics model. In chapter 3.5.4 the method of for decision making under uncertainties based on robust Bayesian belief networks is proposed. Finally, chapter 3.5.5 illustrates the new method with an experiment of circuit board lifecycle decision making.

Most of the existing research on reverse logistics is more interpretive than quantitative in nature [58]. There are also increasing attentions on direct observation methods such as case studies. Survey is still a popular method. More advanced techniques are being used for data analysis in empirical studies such as hypothesis testing. The trend in survey research is moving from exploratory nature to model building and testing.

Previously, Murphy [59] studied the reverse distribution of product from product recalls. Thierry [60] shaped product recovery management by going over the recovery options, from direct re-use to disposing, and by situating them in the supply chain. Carter and Ellram [61] reviewed early work on reverse logistics and subdivided the literature of reverse logistics into transportation, packaging, and purchasing. Recently, there has been studies on how reverse logistics is impacted by product life cycle management, including the opportunities of reuse and recycling, as well as the processes, actors, types of recovery in reverse logistics and the models to support reverse logistics from the business prospective [62].

Among limited numbers of research efforts for reverse logistics decision making, Ravi et al. [63] used the Analytic Network Process approach to provide decision maker a realistic representation of the problem for conduction reverse logistics operations for end-of-life computers. Tan and Kumar [64] presented a decision-making model for manufacturers to maximize their profits in reverse logistics operations. They developed a system dynamic model to complement with prior models. Kara et al. [65] developed a simulation model to address transportation problems associated with reverse logistics network.

Ideally, reverse logistics requires enterprises to collaborate seamlessly and share product information through the whole lifecycle. However, the amount of data related to returned products is much less, than that of traditional products flowing forward in the supply chain since the initiator of reverse logistics usually is end users, who are most likely in the supply chain to have no motivation to keep and share detailed product lifecycle information. Considering the high uncertainties associated with reverse logistics, a new decision support framework is proposed on the base on imprecise probabilities in order to decouple uncertainties from variabilities.

3.5.1 Imprecise Probability

The necessity for an appropriate representation of the uncertainties under consideration in such environments as reverse logistics is important. In general, uncertainty comes from the scarceness of data or lack of knowledge whereas variability is a result of randomness in population. Suppose, for example, only a limited amount of data is available to determine the parameters of a normal distribution during input analysis. Arguably, the precise values of the parameters, the mean μ and the standard deviation σ, defining this distribution are unknown. Imprecise probability is a way to incorporate uncertainties into variabilities.

There have been several representations of imprecise probabilities, for example: behavioural imprecise probability theory [66] models, behavioural uncertainties with the lower prevision (supremum acceptable buying price) and the upper prevision (infimum acceptable selling price). The Dempster-Shafer evidence theory [67, 68] characterizes uncertainties as discrete probability masses associated with a power set of values. Belief-Plausibility pairs are used to measure likelihood. A random set [69] is a multi-valued mapping from the probability space to the value space. The possibility theory [70, 71] provides an alternative to represent uncertainties with Necessity-Possibility pairs. Probability bound analysis [72] captures uncertain information with p-boxes which are pairs of lower and upper probability distributions. All of these forms treat variability and uncertainty separately and propagates them differently so that each maintains its own character during analysis. In this chapter the interval-based imprecise probabilities integrated with Bayesian networks to support decision-making is used.

3.5.2 Bayesian Network

In a dynamic reverse logistics environment, decision makers usually are required to make decisions of material flows based on the latest available information. Bayesian Belief Network (BBN) is able to update probabilities of the states of the variables when learning new evidence. It also utilizes probabilistic independence relationships, both explicitly and implicitly represented in graphical models, in order to make computation efficient for large and complex problems.

Bayesian network has been used widely in different areas, such as solving medicine and industry related problems. In manufacturing and production domain, Bayesian network has been successfully used in on-line alert systems for production plants [73]. It was applied in root cause diagnostics of process variations in technology planning [74]. BBN methodology appears to be an effective tool for explicitly addressing uncertainty and utilizing data from multiple sources [75]. Dynamic Bayesian network can also be used as the knowledge base of the reasoning systems for the supply chain diagnostics and prediction, vendor appraisal, customer assessment, evaluation of strategic or technical alliance, and others [76].

In this case study interval-based imprecise probabilities are integrated into Bayesian networks in order to improve the robustness of reasoning under uncertainties. We apply the robust Bayesian networks to decision support of reverse logistics management.

3.5.3 Decision support in the Closed-loop Supply Chain Framework

Supply chain network design is commonly recognized as a strategic issue of business success. The location of production facilities, warehouses, and transportation strategies are major keys of supply chain performance. Reverse logistics should be taken into consideration during the design of the support network such as location and capacity of warehouses, plants, choice of outsourcing parties, distribution channel and supporting technology. The captured information about returns should be integrated with forward supply chain information to achieve optimum planning and reduction of costs.

The closed-loop supply chain with a general framework of the forward and reverse material flows in product lifecycle management is modelled. This framework includes the major scenarios that can take place in the recovering of the used product, as shown in Figure 34.

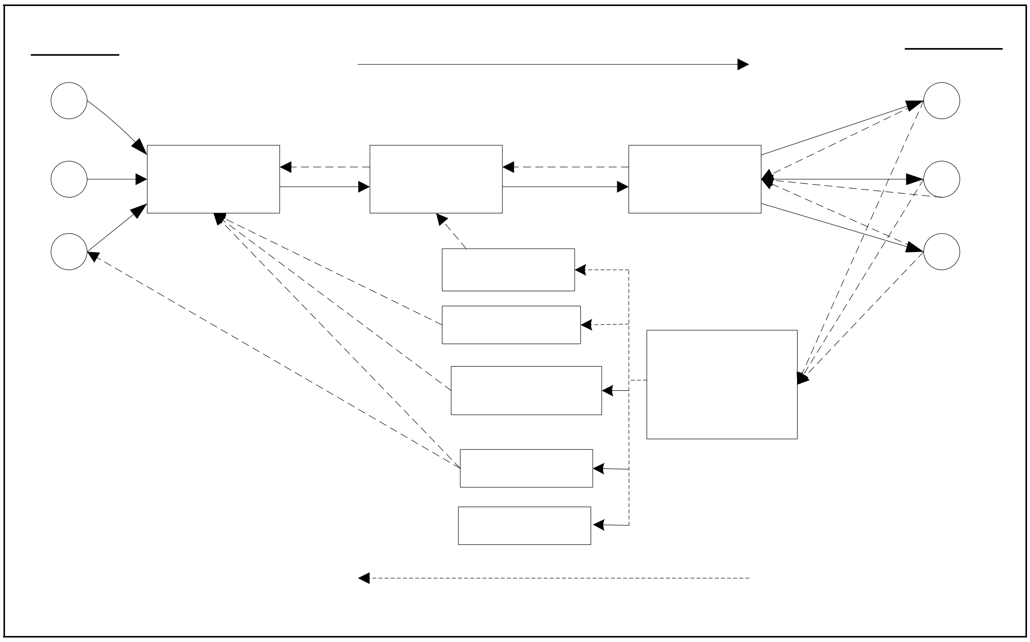

Figure 34. General Supply Chain Framework

Although, it is a closed loop logistics, some materials or products will still be disposed due to technical reasons (e.g. dissatisfactory of product). Collection refers to all activities of rendering used products and physically moving them to some point for further treatment. Sorting and inspection are the operations that determine whether a given product is reusable and which method to apply. Thus, sort and inspect result in splitting the flow of used products according to the distinct types of recovery such as repair, reuse, remanufacturing and recycle.

There are two different reverse logistics practices in industry. In Europe, reverse logistics practices are carried out in house. This approach leads to faster recovery rate, direct interaction with customers and control over revenue from the recovered products. However, disadvantages of the approach exist such as the increased complexity of production planning. In contrast, in the U.S., reverse logistics activities are outsourced. This is done because many businesses see the entire concept of reverse logistics is unmanageable. As a result, they choose to outsource the problem instead of managing it [77].

A third party collector can be more resourceful and technically advanced in collection and recovery of returned products. Since there is no interference with original manufacturer’s production line, planning and control can be simplified. However, technical details of products will be revealed. Original Equipment Manufacturer (OEM) will not be able to realize the full potential of the revenues generated by product recovery.

To support a set of decision makers working together as a group, a collaborative IDSS has some special technological requirements of hardware, software, people and procedures. Collaborative IDSS software also needs special functional capabilities, in addition to the capabilities of single user DSS software, such as anonymous input of the user's ideas, listing group members' ideas, voting and ranking decision alternatives IDSS will have the ability to take the integrated data stored within this database and transform it, through various analysis techniques. ERP systems are able to achieve integration by bringing together data from different sources within the firm. This may include disparate databases that exist across different functional units, thus helping the firm to gain a more complete and realistic picture of all the data they hold. ERP systems have traditionally not been able to provide satisfactory support for transforming data, and enabling decision makers to discover and learn, ultimately turning this data into knowledge. This is where DSS have been able to give strong support. The human component of group IDSS should include a group facilitator, who leads the session by serving as the interface between the group and the computer systems [78].

In this computational experiment the framework of collaborative IDSS system will be applied for group decision support in the reverse logistics field. In the case of in-house reverse logistics the system will be internal. In case of outsourced reverse logistics system will be external. The third party collector will use IDSS for the collection and distribution of information between supply chain participants. The information available in the supply chain network is scarce. Often the decision should be made in conditions, when the information is only partly available. For this reason the robust BBN mechanism to support decision-making is used. System will be able to ask the required data from other systems and perform data mining process. Cleaned data or information will be used in further process of decision support. System will know the algorithm of the process and will be able to propose what should be the next activity, if the result of the previous activity is known.

System will help to estimate what activity must be performed next based on system logic. System will be able to calculated posterior probability interval, based on prior information and received results of performed activities. User should perform activities until the posterior probability of success will be in acceptable range. In case the required posterior probability of success can not be achieved even after corrective activities, the returned product will be disposed.

In Figure 35 the framework for the proposed IDSS system is shown. It is the circle, which included ERP systems of different participants and management mechanism, or IDSS system. First of all, the data about the returned product will be inserted into the IDSS system. The data about returns will be transmitted to the ERP systems of participants. With the IDSS, it will be possible to track information about returned products during the whole life cycle, until the product is disposed. It enables the participants to be prepared for a situation, when the product should be repaired, remanufactured or reused. Also, the participants should be able to estimate the probability that the product will be disposed and the new products should be produced instead. This information will be used as evidences to support the decision-making.

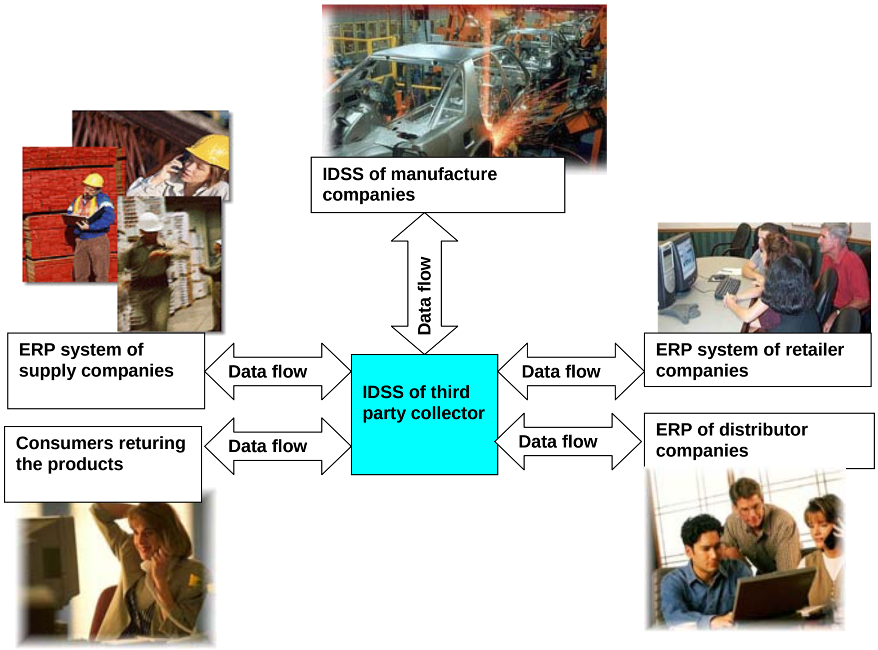

Figure 35. IDSS system used for reverse logistics in the collaborative supply chain network

To manage the reverse flow of materials, decisions of which path should be taken such as at the stage of collection and sorting need to be made. The highly uncertain factors related to the conditions and the residual values of returned product increase the risk; therefore the difficulty of decision-making. In order to achieve the ultimate goal of long-term profitability and sustainability in the complete life cycle of products, decision makers usually need more information to assess the available options. A set of situations including the worst-case and best-case scenarios should be differentiated and compared. A new method of decision making under uncertainties based on the robust Bayesian Belief Network is developed by authors.

3.5.4 Robust Bayesian Belief Networks

One can regard the Intelligent Decision Support system as a consultant that supplies various models and assessments, elicits others from the user, combines all judgments, and finally informs the user "if you accept all these judgments then you should draw these conclusions". Robust analysis is concerned with the sensitivity of the results of the Bayesian analysis to the inputs for the analysis. Global robustness is focused on replacing a single prior distribution by a class of priors and developing methods of computing the range of the ensuring answers as the prior varied over the class.

The usual practical motivation underlying robust Bayesian analysis is the difficulty in assessing the prior distribution. Robustness with respect to the prior stems from the practical impossibility of eliciting a unique and precise distribution. Similar concerns apply to the other elements (likelihood and loss functions) considered in Bayesian analysis. The main goal of Bayesian robustness is to quantify and interpret the uncertainty induced by partial knowledge of one (or more) of the three elements in the analysis [79].

The traditional robust statistics uses a neighbourhood concept, called *ε-contamination model*, given by:

$$\Gamma_\varepsilon = \{P : P = (1-\varepsilon)P_0 + \varepsilon Q, Q \in \vartheta\}$$

Where Γ_ε is the ε-neighbourhood of the probability P_0, and ϑ is called the class of contaminations that contains some arbitrary probability measurement Q. The popularity of the class arises, in part, from the ease of its specification and, in part, from the fact that it is typically easily handled by the traditional precise probability theory. Here a different approach is taken in order to characterize robustness with interval probabilities.

The uncertainties in stochastic processes by a set of probabilities are used. The interval probability of event *A* is defined as (11):

$$\mathbf{P}(A) := [\underline{P}(A), \overline{P}(A)] \quad (0 \le \underline{P}(A)) \le \overline{P}(A) \le 1) \tag{11}$$

In the case $\underline{P}(A) = \overline{P}(A)$, the degenerated interval probability *P(A)* becomes a traditional precise probability.

Given uncertainties involved in prior probabilities, the estimation of imprecise posterior probabilities is based on the Generalized Bayes' Rule (GBR) [80] (12, 13, 14, 15):

$$\underline{P}(B_j \mid A) = \inf\left[\mathbf{P}(B_j \mid A)\right] = \frac{\underline{P}(A \mid B_j)\underline{P}(B_j)}{\sup\left[\sum_{i=1}^{n} P(A \mid B_i)P(B_i)\right]} \tag{12}$$

$$\overline{P}(B_j \mid A) = \sup\left[\mathbf{P}(B_j \mid A)\right] = \frac{\overline{P}(A \mid B_j)\overline{P}(B_j)}{\inf\left[\sum_{i=1}^{n} P(A \mid B_i)P(B_i)\right]} \tag{13}$$

A simplified version of the Eq.(2) and Eq.(3) is

$$\underline{P}(B_j \mid A) = \frac{\underline{P}(A \mid B_j)\underline{P}(B_j)}{\underline{P}(A \mid B_j)\underline{P}(B_j) + \sum_{\substack{i=1 \\ i \neq j}}^{n} \overline{P}(A \mid B_i)\overline{P}(B_i)} \tag{14}$$

$$\overline{P}(B_j \mid A) = \frac{\overline{P}(A \mid B_j)\overline{P}(B_j)}{\overline{P}(A \mid B_j)\overline{P}(B_j) + \sum_{\substack{i=1 \\ i \neq j}}^{n} \underline{P}(A \mid B_i)\underline{P}(B_i)} \tag{15}$$

The GBR gives the lower and upper bounds of all possible posterior probabilities given the ranges of priori probabilities. It is used to update the initial prevision $\underline{P}$ after learning that event B has occurred. Upper and lower probabilities, $\overline{P}$ and $\underline{P}$, are specified for all subsets of the sample space Ω, and it is required to construct conditional upper and lower probabilities $\overline{P}(\cdot \mid B)$ and $\underline{P}(\cdot \mid B)$, e.g. to update beliefs after observing the event B.

In the probabilistic reasoning, the interval Baysian decision-making theory follows the principles of coherence. That is, $0 \le \underline{P}(A) \le \overline{P}(A) \le 1$, $0 \le \underline{P}(B_j \mid A) \le \overline{P}(B_j \mid A) \le 1$, and $\overline{P}(B_j) + \sum_{i \neq j} \underline{P}(B_i) \le 1 \le \underline{P}(B_j) + \sum_{i \neq j} \overline{P}(B_i)$ for all $j = 1, \ldots, n$ in Eq.(14) and Eq.(15). They can therefore be justified though the behavioural interpretation of lower previsions. The GBR is used to update coherent imprecise probabilities.

Upper and lower previsions are used to compare actions and make decisions in the following way. Now it is necessary to choose an action from a finite set of possible actions $\{a_1, a_2, ..., a_k\}$, where the utility $U(a,\omega)$ of action a depends on the unknown situation ω.It is assumed that utilities are specified precisely; otherwise the decision problem is more complicated.) Define a reward X_j by $X_j(\omega) = U(a_j, \omega)$ for each $j = 1,2,...,k$. To compare two actions a_i and a_j for decision-making the upper and lower previsions are calculated $\overline{P}(X_i - X_j)$ and $\underline{P}(X_i - X_j)$ on the basis of available information. Then action a_i is preferred to a_j if $\underline{P}(X_i - X_j) > 0$, a_j is preferred to a_i if $\overline{P}(X_i - X_j) < 0$, and if neither of the conditions holds there is insufficient information to determine the preference. The action a_i is maximal if there is no other action a_j that is preferred to a_i.

In the next section, the new robust decision making approach is illustrated with an experiment of returned spacecraft circuit boards. The comparison of different actions will be shown. The application of the Generalized Bayesian Rule theory for the monitoring of project success probability is described.

3.5.5 Application to Spacecraft Circuit Board reuse

The robust decision making approach is applied as an experiment of spacecraft circuit board reuse. Space systems are inherently risky because of the technology involved and the complexity of their activities. The significant presence of uncertainties requires good management of risks during the development of space systems. Space shuttle is recognized as the world's first reusable space transportation system. NASA reuses the space shuttle elements, which is one of the major reverse logistics practitioners to recover and recapture the value of all components. Capturing of the uncertain conditions of these reusable components is critical in order to prevent disaster. Since all phases in the spacecraft life cycle are associated with risks, development of a robust tool to calculate the accumulated cost and assess risks is essential in this industry.

When previously used circuit boards arrive at the reverse logistics collector, their conditions will be tested. The IDSS system will help the collector to decide what action should be performed to the returned circuit board. After the test, appropriate actions should be selected. Boards are repaired, remanufactured, reused or disposed see Figure 36. Testing is performed in-house, others performed by corresponding supply chain participant. After completing of any action, the lower and upper bounds of project success probability are updated. The decision maker will monitor the posterior probabilities after every activity, until the probability of project success is high enough.

The different tests for estimation of the condition of the used components are performed. This data is used for the construction of Bayesian network. Bayesian network will be used as a decision support tool, after the information is available. The decision of interest is based on received data. IDSS will be able to collect and manage information flow in the supply chain network. The Robust Belief Network mechanism will be used for decision support purposes. The IDSS will be able to collect required data directly from the ERP systems of collaborative enterprises and track the returned products. All participant of supply chain network will be able to check in real time in what stage and in what location the returned product is, and what is the probability of project success if this product is reused. It means that decision must consider the latest available information. Project success monitoring process will be supported by Bayesian network, which recalculates posterior data after the new information is added. But in our case the prior probability is uncertain. The idea is to find out how to make decisions in such situations. The worst case situation is selected, because it is the most important scenario in the application. Any kind of fault is very costly.

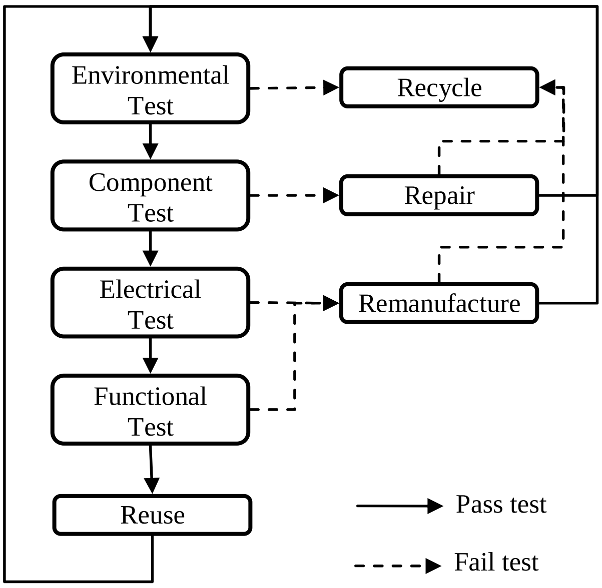

Figure 36. State diagram of performed tests and activities

The decisions must be made with a noticeable presence of uncertainty because not enough prior information is available. As shown in Figure 36, four tests are performed: T1- Environmental test; T2 - Component test; T3 - Electrical Test; T4 - Functional Test. If the result of any test is negative, the appropriate action including recycle, repair, remanufacture, and reuse will be performed. The number of tests - n is small. The posterior probabilities that a project will be successful are used for the decision-making. It is required to estimate the probability that a project will be successful if an action of reuse, remanufacture, or repair for some circuit boards is performed, i.e., $P(project\ success = yes \mid P_{reuse,} P_{remanufacture,} P_{repair})$. As the prior probabilities are given in intervals, the posterior probability that is received will also be an interval.

The range of the project success should be calculated. The narrower is the range, the less indeterminacy our decision will have. The network is built on the base of prior information. The intervals of project success rate can be calculated accordingly to Eq. (14) and Eq.(15). The GBR tool is used in Bayesian Network software "Netica" for calculations. The original software is only able to calculate based on precise probabilities. Therefore, two or more networks are constructed: one for minimum bound and another for maximum bound calculation.

A simple Bayesian network experiment consisting of three nodes is used here to introduce how robust Bayesian networks are constructed. Relations of Environmental test, Component test, and Project Success are built as in Fig.37. Component Test is related to Project Success, and Component Test is related to both Environmental Test and Project Success. The lower and upper bounds of prior probabilities and likelihood functions for calculations are given in Table 7. Prior probabilities for a simple experiment Bayesian network.

Table 7. Prior probabilities for a simple experiment Bayesian network

Known prior probabilities	Lb	Ub
P(Envir.Test =OK|ProjectSuccess = Yes)	0.97	0.99
P(Envir.Test =OK|ProjectSuccess = No)	0.75	0.8
P(Envir.Test =Failed|ProjectSuccess = No)	0.2	0.25
P(Envir.Test =Failed|ProjectSuccess = Yes)	0.01	0.03
P(Comp.Test =OK|ProjectSuccess = Yes;Envir.Test=OK)	0.98	0.995
P(Comp.Test =OK|ProjectSuccess = No)	0.6	0.7
P(Comp.Test =Failed|ProjectSuccess = no;Envir.Test=OK)	0.3	0.4
P(Comp.Test =Failed|ProjectSuccess = Yes;Envir.Test=OK)	0.005	0.02
P(ProjectSuccess = Yes)	0.90	0.95
P(ProjectSuccess = No)	0.05	0.10

To calculate the lower bound network $\underline{P}(\Pr.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK)$ and $\overline{P}(\Pr.Succ. = No \mid Env.Test = OK; Comp.Test = OK)$, the probability bounds listed in Table are used. It should be noticed that

$$\overline{P}(\Pr.Succ. = No \mid Env.Test = OK; Comp.Test = OK)$$

$$= 1 - \underline{P}(\Pr.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK)$$

which follows the consistency principle.

Table 8. Probabilities for the nodes of the Bayesian network lower bound

Component test node probabilities				Enviromental test node probabilities			Projects success node probabilities	
Project Success	Envir.Test	OK2	Failed 2	Project Success	OK1	Failed1	Project Success	
Yes	OK	(lb) 0.98	(ub) 0.02	Yes	(lb) 0.97	(ub) 0.03	Yes	(lb) 0.9
No	OK	(ub)0.7	(lb) 0.3	No	(ub) 0.8	(lb) 0.2	No	(ub)0.1

To calculate the upper bound network $\overline{P}(\Pr.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK)$ and $\underline{P}(\Pr.Succ. = No \mid Env.Test = OK; Comp.Test = OK)$, the probability bounds listed in Table are used.

Table 9. Probabilities for the nodes of the Bayesian network upper bound

Component test node probabilities				Enviromental test node probabilities			Projects success node probabilities	
Project Success	Envir.Test	OK2	Failed 2	Project Success	OK1	Failed1	Project Success	
Yes	OK	(ub) 0.995	(lb)0.005	Yes	(ub)0.99	(lb) 0.01	Yes	(lb) 0.95
No	OK	(lb) 0.6	(ub)0.4	No	(lb)0.75	(ub)0.25	No	(ub)0.05

Figure 37 shows the calculated results from the software tool. The results are $P(\Pr oj.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK) = [0.939, 97.7]$ and $P(\Pr oj.Succ. = No \mid Env.Test = OK; Comp.Test = OK) = [0.0235, 0.0614]$.

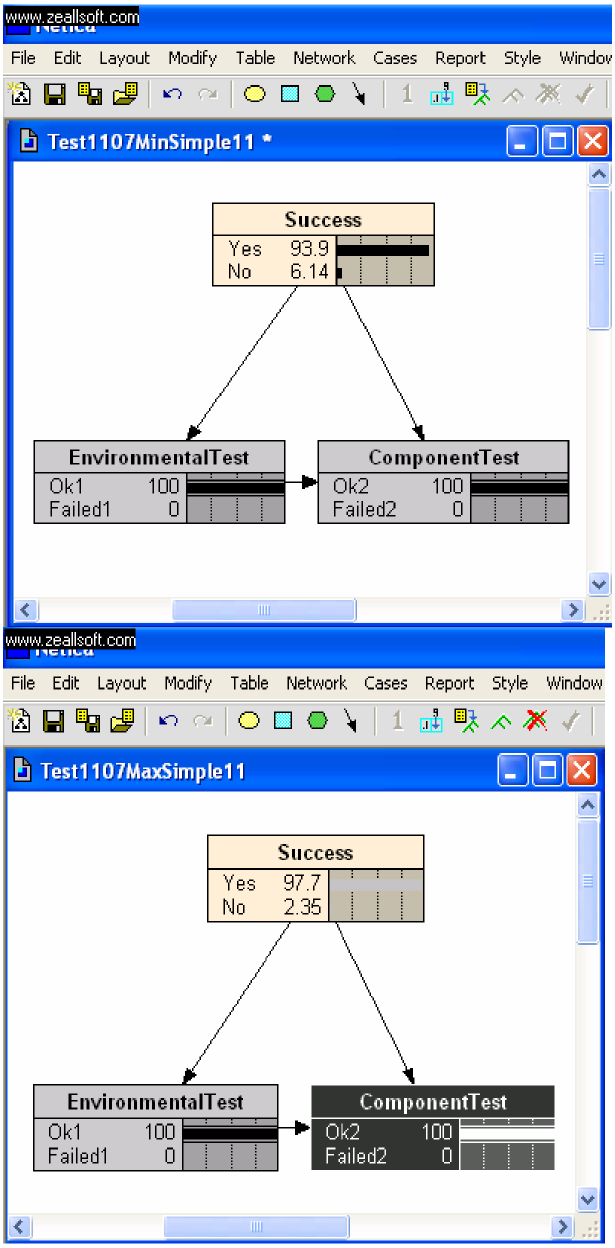

Figure 37. Probability of success

The results are verified by the following manual calculations.

$$\underline{P}(\Pr.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK) = \inf\left[P(\Pr.Succ. = yes \mid Env.Test = OK; Comp.Test = OK)\right]$$

$$= \frac{\underline{P}(Env.Test = OK \mid \Pr.Succ. = yes)\underline{P}(Comp.Test = OK \mid \Pr.Succ. = yes; Env.Test = OK)\underline{P}(\Pr.Succ. = yes)}{\begin{bmatrix}\underline{P}(Env.Test = OK \mid \Pr.Succ. = yes)\underline{P}(Comp.Test = OK \mid \Pr.Succ. = yes; Env.Test = OK)\underline{P}(\Pr.Succ. = yes) \\ + \overline{P}(Env.Test = OK \mid \Pr.Succ. = No)\overline{P}(Comp.Test = OK \mid \Pr.Succ. = No; Env.Test = OK)\overline{P}(\Pr.Succ. = no)\end{bmatrix}}$$

$$= \frac{0.97 \times 0.98 \times 0.9}{(0.97 \times 0.98 \times 0.9) + (0.8 \times 0.7 \times 0.1)} = 0.939$$

$$\overline{P}(\Pr.Succ. = No \mid Env.Test = OK; Comp.Test = OK) = \sup\left[P(\Pr.Succ. = No \mid Env.Test = OK; Comp.Test = OK)\right]$$

$$= \frac{\overline{P}(Env.Test = OK \mid \Pr.Succ. = No)\overline{P}(Comp.Test = OK \mid \Pr.Succ. = No; Env.Test = OK)\overline{P}(\Pr.Succ. = No)}{\begin{bmatrix}P(Env.Test = OK \mid \Pr.Succ. = No)\overline{P}(Comp.Test = OK \mid \Pr.Succ. = No; Env.Test = OK)\overline{P}(\Pr.Succ. = No) \\ + \underline{P}(Env.Test = OK \mid \Pr.Succ. = Yes)\underline{P}(Comp.Test = OK \mid \Pr.Succ. = Yes; Env.Test = OK)\underline{P}(\Pr.Succ. = yes)\end{bmatrix}}$$

$$= \frac{0.8 \times 0.7 \times 0.1}{(0.8 \times 0.7 \times 0.1) + (0.97 \times 0.98 \times 0.9)} = 0.0614$$

$$\overline{P}(\Pr.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK) = \sup\left[P(\Pr.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK)\right]$$

$$= \frac{\overline{P}(Env.Test = OK \mid \Pr.Succ. = Yes)\overline{P}(Comp.Test = OK \mid \Pr.Succ. = Yes; Env.Test = OK)\overline{P}(\Pr.Succ. = Yes)}{\begin{bmatrix}P(Env.Test = OK \mid \Pr.Succ. = Yes)\overline{P}(Comp.Test = OK \mid \Pr.Succ. = Yes; Env.Test = OK)\overline{P}(\Pr.Succ. = Yes) \\ + \underline{P}(Env.Test = OK \mid \Pr.Succ. = No)\underline{P}(Comp.Test = OK \mid \Pr.Succ. = No; Env.Test = OK)\underline{P}(\Pr oj.Succ. = no)\end{bmatrix}}$$

$$= \frac{0.99 \times 0.995 \times 0.95}{(0.99 \times 0.995 \times 0.95) + (0.75 \times 0.6 \times 0.05)} = 0.9765$$

$$\underline{P}(\Pr.Succ. = No \mid Env.Test = OK; Comp.Test = OK) = \inf\left[P(\Pr.Succ. = No \mid Env.Test = OK; Comp.Test = OK)\right]$$

$$= \frac{\underline{P}(Env.Test = OK \mid \Pr.Succ. = No)\underline{P}(Comp.Test = OK \mid \Pr.Succ. = No; Env.Test = OK)\underline{P}(\Pr.Succ. = No)}{\begin{bmatrix}P(Env.Test = OK \mid \Pr.Succ. = No)\underline{P}(Comp.Test = OK \mid \Pr.Succ. = No; Env.Test = OK)\underline{P}(\Pr.Succ. = No) \\ \overline{+P}(Env.Test = OK \mid \Pr.Succ. = Yes)\overline{P}(Comp.Test = OK \mid \Pr.Succ. = Yes; Env.Test = OK)\overline{P}(\Pr.Succ. = yes)\end{bmatrix}}$$

$$= \frac{0.75 \times 0.6 \times 0.05}{(0.75 \times 0.6 \times 0.05) + (0.99 \times 0.995 \times 0.95)} = 0.0235$$

The probability that Project is successful given that the Environmental Test is OK and Component Test is OK is [93.9,97.675]. The probability that Project is not successful given that the Environmental Test is OK and Component Test is OK is [0.0235, 0.0614].

The same network construction principle is used in the bigger Bayesian network, which includes all required nodes for four tests in the model of Figure 36. The decisions should be made according to the posterior probability that the project will be successful, after the test results or information about performed activities is received. The network will update the probability of project success and support the decision maker. In our experiment after the test results are received the posterior probability of our project success is. $P(\Pr oj.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK; Electric.Test = OK) = [99.1, 99.3]$

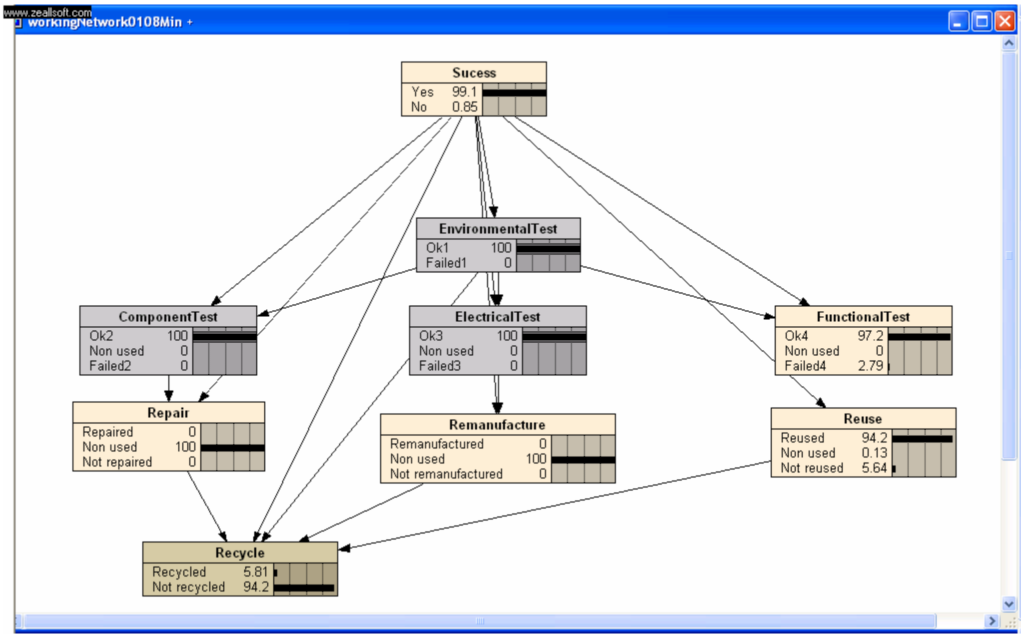

Figure 38.Calculation of project success probability lower bound

The IDSS system suggests to perform activities until the probability bounds of project success will be higher than the required one or [98.8, 99.6]. The decision support process is performed in 4 steps:

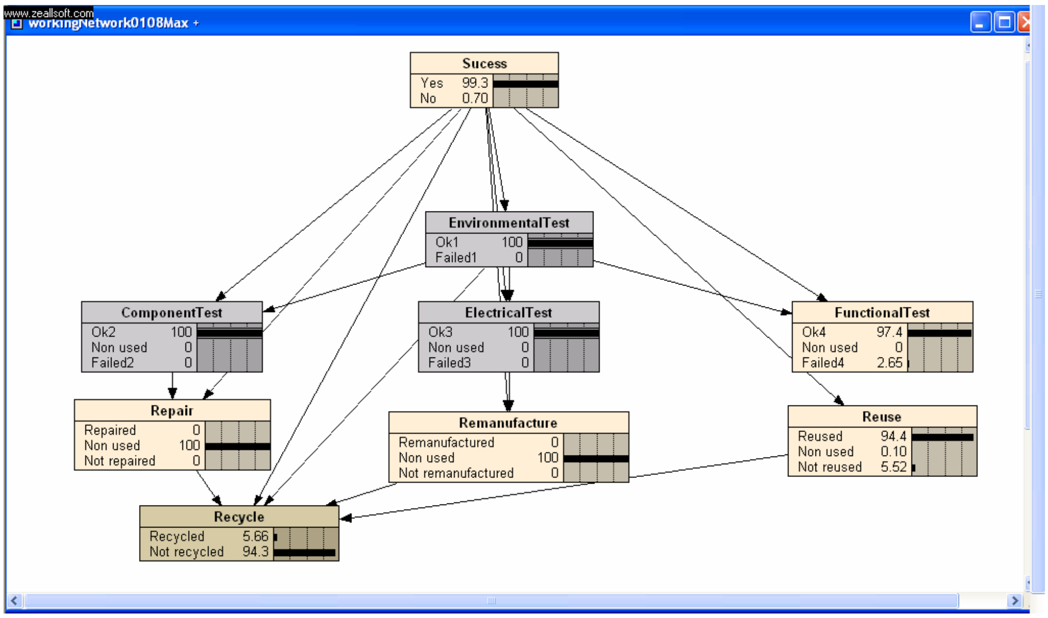

Figure 39. Calculation of project success probability upper bound

Step 1. After a board passes the Environmental Test, the posterior probability $P(\Pr oj.Succ. = Yes \mid Env.Test = OK) = [91.6,95.8]$ is received. The probabilities for different activities will be also updated: $\Pr epaired = [1.72,4.75]; \Pr emanuf. = [0.5,1.87]; \Pr eused = [87.4,91.3]; \Pr ecycle = [8.94,13]$;

System is able to calculate also the posterior probability to estimate what is the probability of project success after different activities are successfully performed:

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK; \mathrm{Re}\ paired = Yes) = [27.5,38.2]$;

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK; \mathrm{Re}\ manuf = Yes) = [95,96.9]$;

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK; \mathrm{Re}\ use = Yes) = [99.5,99.8]$;

So, the system will conclude, that the best activity to perform is to reuse the board, but the probability of project success in not high enough and it is better to perform component test.

Step 2. If the board passes the component Test, the posterior probability $P(\Pr oj.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK) = [97.3,98.3]$ is received. The probabilities for different activities will be also updated: $\Pr epaired = [0]; \Pr emanuf. = [0.5,1.95]; \Pr eused = [92.5,93.5]; \Pr ecycle = [6.63,7.61]$;

System will recalculate also the posterior probabilities to estimate what is the probability of project success after different activities are successfully performed:

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK; \mathrm{Re}\ paired = Yes) = not\_available$;

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK; \mathrm{Re}\ manuf = Yes) = [97.9,99.2]$;

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK; \mathrm{Re}\ use = Yes) = [99.08,99.75]$;

It means that after component test the system will understand that if the board is passed the comp. test the repair activity should not be used any more. The best activity to perform is to reuse the board, but the probability of project success in not high enough and system will suggest performing electrical test.

Step 3. If the board passes the electical Test, the posterior probability $P(\Pr oj.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK; Electr.Test = OK) = [99.1,99.3]$ is received. The probabilities for different activities will be also updated:

$\Pr epaired = [0]; \Pr emanuf. = [0]; \Pr eused = [94.2,94.4]; \Pr ecycle = [5.66,5.81]$;

System will recalculate also the posterior probabilities to estimate what is the probability of project success after different activities are successfully performed:

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK; Electr.Test = OK; \mathrm{Re}paired = Yes) = non\_valid$;

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK; CompTest = OK; Electr.Test = OK; \mathrm{Re}manuf = Yes) = non\_valid$;

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK; Comp.Test = OK; \mathrm{Re}\ use = Yes) = [99.955,99.963]$;

Step 4. It means that after the electrical test the system will understand that if the board is passed the component and electrical tests the repair and remanufacture activities should not be used any more. When the Electrical Test is also completed successfully the posterior probability of the project success will be

$P(\Pr oj.Succ. = Yes \mid Env.Test = OK, Comp.Test = OK, Electr.Test = OK) = [99.2,99.5]$

as seen in Figure 38 and Figure 39. The best activity to perform is to reuse the board. The probability of project success in high enough and system will suggest not to perform functional test. In such way, the IDSS monitor the upper and lower bounds of the probability of success until the lower probability of success is high enough for robust decision making. Also, it is possible to track the probability of success after every activity and decide what should be made next. This enables us to increase the effectiveness of reverse logistics operations.

3.5.6 Conclusion of section 3.5

In this chapter was presented an interval based robust decision support approach to support closed loop supply chain management. This model explicitly differentiates uncertainty from variability and incorporates uncertainty factors due to lack of information. Interval probabilities are used to represent classes of possible variations instead of precise ones. This allows considering all possible scenarios between extreme cases during probabilistic reasoning. A Generalized Bayes' rule was developed based on interval probabilities such that reliable decision making can be supported. This new approach is to improve the robustness of decisions under high uncertainties.

3.6 Methodology for the IDSS development

There are well-documented approaches and methodologies for Information System Development (ISD). These approaches and methodologies can all be related to Software Development Life Cycle (SDLC), a paradigm focusing on ISD in organization and other closed-domain systems. Recent developments in agent-oriented software engineering extend this paradigm to cover intelligent agents and multi-agent systems. Intelligence is the ability to learn or understand or to deal with new situations. When we apply this to software agents, it refers to the agent's ability to accept different user's statements and goals and carry out the task delegated to it [81].

Almost all existing ISD approaches and methodologies can be grouped under one paradigm characterized by the System Development Life Cycle. The basic structure of SDLC starts with an initial feasibility study, going through stages like system analysis and design, implementation, and finally entering into the stage of maintenance. The cost of failure is low for agents compared with IDMSS or other information systems in the organisational domain. New paradigm was developed for Web-based agents (see table 10).

Table 10. Comparison between SDLC paradigm and new paradigm

	SDLC Paradigm	New Paradigm
Requirement Analysis	Defined by Users	Defined by Imitation
System Design	Encourage close developer-user interaction	No interaction needed
System Implementation	Controlled by system user or stakeholders	Contingent on environment
System Maintenance	Clearly separated from implementation	Not separated from implementation

Accordingly to this new paradigm the comparison-shopping agent was developed. In general, the environment for a comparison-shopping agent was far more complex than those for traditional i-DMSS. If we compare the system development for comparison-shopping agent with i-DMSS in a closed domain, we can find that:

First, there was no specific user involved in requirement analysis for the design of comparison-shopping agent. Since comparison-shopping agents are designed for the general public. It was impossible to accommodate a specific user's preference. As an other established agents. Actually, imitation has replaced requirement analysis for the development of most comparison-shopping agents.

Secondly, there is no clear stage boundary between system design and implementation. Because comparison-shopping agents were competing for the same users (online shoppers), they have to incorporate new features constantly. As a result, the system design and implementation were not separated at all.

Thirdly, there is no clear boundary between system implementation and maintenance. Since comparison-shopping agents are placed in an open environment for use, they must be ready for any new development based on changing demands from online shoppers or pressures from their innovative peers. So, there was no completion of the system. There were only irregular intervals between system maintenance and further development. In other words, there was no life cycle for comparison-shopping agents [82].

The summary of the characteristics of this new paradigm reflected in the case studies above into three aspects: start simple in design or by imitation, blend environment solutions to technical challenges, and grow between stasis and punctuation. People always want to minimize their effort as long as they can reach the minimum requirements for the decision quality. Recent controlled experiments also prove that decision makers do not use advanced functions provided by DSS as long as they can meet their minimum decision criteria by using those less advanced functions. This is because using advanced functions requires more effort to learn though it could improve the decision quality. The technical challenges of system design are not necessarily overcome through technical evolution or revolution. Instead, major challenges are overcome through reorganizing the relationship with environments. This is a very important feature that differentiated the development paradigm of comparison-shopping agents from those of i-DMSS in a closed domain. [83].

DSS design and development processes have been the subject of several comparative studies in the past. Some processes clearly focus on "decision making", others on "systems engineering", and others on both. It is not enough to define a DSS in terms of inputs and outputs and to specify particular data and reports. A system that is usable and useful should be designed and delivered as soon as possible, but it should also be flexible enough to allow rapid extension and addition of routines.

DSS development methodology popular in the DSS literature that can be broken down into two broad parts: an "action plan", made of four phases described in Table, and the ROMC methodology, a "process-independent model for organizing and conducting systems analysis in DSS". The ROMC approach is made of four components: representations, operations, memory aids, and control mechanisms, which are described in Table 11 [83].

Table 11. The DSS action plan

Phase	Description
I. Preliminary study and feasibility assessment	Survey the user base and assess user needs. Conduct pilot projects to ascertain general characteristics and the implications to DSS needs.
II. Development of the DSS environment	Form a DSS group, articulate its mission, and define its relationships with other organizational units. Establish a minimal set of tools and data and operationalize them.
III. Development of the initial specific DSS	Identify, analyze, and design the initial specific DSS with the users.
IV. Development of subsequent Specific DSS	Assess needs for subsequent specific DSS. Develop subsequent DSS based on the initial one.

Table 12. The ROMC components

Component	Description	Examples
Representations	Conceptualizations used as methods of communication between the user and the DSS	Charts, tables, reports, input forms, equations
Operations	Activities necessary for the DSS to perform or facilitate the generation and delivery of the representations	Diagnosing and structuring problem; gathering manipulating, and validating data; generate and assign risks to alternatives; simulate results of alternatives
Memory aids	Components intended to provide support to the use of the various identified representations and operations	Databases, workspaces, links, triggers alerting DSS users to perform specific operations, user profiles
Control mechanisms	Aids intended to help decision makers use representations, operations, and memory aids to synthesize a decision-making process based on their individual styles, skills, and knowledge	User interface aids, such as menus of function keys; help commands, tutorials; editing tools.

3.6.1 Defining the system type

The first requirement for efficient modelling is a clear statement of the model's purpose. Without this assertion, it is difficult to know what should be included in a model, or even to know whether static modelling or dynamic modelling will be needed.

A model cannot represent everything that is in any way connected to a system. Effective modelling requires restricting the range of a model to include only things that are part of the system of interest.

Realize that any line drawn between system and non-system is an artificial distinction that is made in order to reduce a model's range to something that can be studied within a reasonable period of time.

The next phase is determining from whose perspective the diagram is going to be developed. If you look at all the people who can answer the questions, one position will emerge that has sufficient scope to combine the other perspectives. This position defines the *viewpoint* of the IDEF diagram [83].

3.6.2 Input-output analysis

Process view model focuses mainly on how to organize internal activities into a proper manufacturing process according to the enterprise goals and system restrictions. Traditional function-decomposing-oriented modelling method IDEF0, which set up the process based on activities (functions), can be used in manufacturing process modelling.

Information view organizes the information necessary to support the enterprise function and process using an information model. Data for company are an important resource, so it is necessary to provide a method to describe or model the data, such as data structures and relationships among data. The most commonly used IDEF1X model.

As information about a system accumulates, actual modelling can begin. A model begins as a set of questions that help focus the diagram to a single issue.

Typical questions related to a workflow scenario might be:

How much time is available and what is the duration of the processing?

Which resources are assigned to which tasks?

Can some steps happen concurrently?

Considered hereinafter FMS analysis is not use for simulation IDEF3 method, because Meta Software company software allows start simulation directly from IDEF0 model.

Classification of inputs outputs is important task to start with. We should be understood what are the inputs and outputs of our system. It is proposed to use IDEF methodology for input-output analysis [VIII].

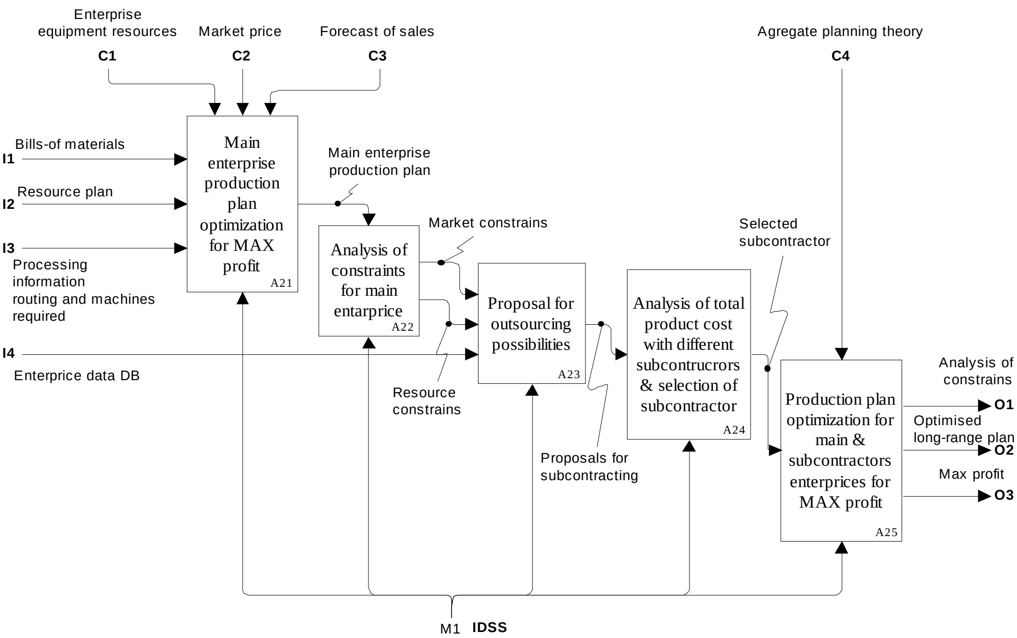

Figure 40. IDEF0 diagram of production plan optimization

The IDSS accommodates data from several business functions. New system must be able to set itself for the communication with the systems of the partner enterprises. It must be able to understand which system using the partner enterprise and to select appropriate module for communication. A diagram of production plan optimization is introduced in Figure 40. For description IDSS business functions is used IDEF0 method. The IDEF0 model reflects how system functions interrelate and operate; standard box/arrow each side of a function box has a relationship:

input arrows interface with the left side of a box; control - with the topside; output - with the right side, and mechanism - with the bottom side of the box. Main benefit of IDEF0 model is that it may be transferred to the simulation model.

Simulation is a very active branch of computer science, which consists of analysing the properties of theoretical models of the surrounding world. Generally, these models are set up in the form of mathematical relationships between variables representing physical values, which can be measured in reality. They are based on the definition of a cause and effect relationship between the input variables and output variables [84]. The main process is divided to smaller sub-processes, which is possible to look independently and to describe it using the IDEF methodology. The main processes were visualised in Arena simulation tool.

This enables to make sure more exactly which data every sub-process will require on what moment, and analyse the inputs and outputs of all sub-processes. Also, it will be possible to get results of simulation in the form of report for further analysis [VIII].

3.6.3 Description and use of prototype system model

It is proposed to use system prototype in order to understand the real system involved in a particular problematic situation. In association with this prototype model, then a structured procedure to identify and describe the actual systems content, and examine the conditions necessary for the effective operation and control of manufacturing organisations could be formulated. Prototype system model tells us, at least at a conceptual level, what a properly designed and implemented system should look like. In association with the prototype system model, system identification and description is one of the essential skills, which any system analyst must learn [VIII].

3.6.4 Implementation of IDSS

The process of system implementation [VIII] is divided into several stages: diagnostics, analysis and design, implementation of IDSS system, IDSS solution support (Figure 41).

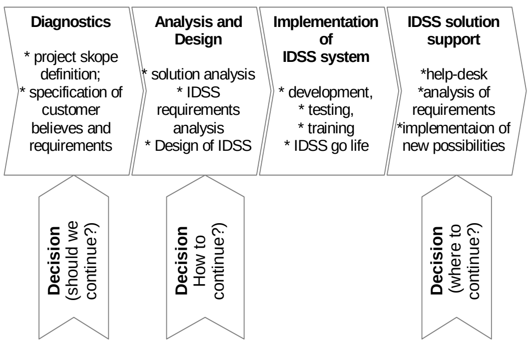

Figure 41. The process of IDSS implementation

3.6.5 Diagnostics

During this stage the enterprise requirements and problems will be analysed. It will be decided what role will be given to IDSS system. It will be estimated what are the critical processes of the company and what will be the base for decision support. The result will be the prototype of the desired system, which includes all the requirements IDSS must satisfy [VIII].

3.6.6 Conclusion of section 3.6

During this stage the IDSS system should be tested, improved and implemented. All key users will be trained to use new system. It is possible to make some minor changes in the IDSS design. At this stage the working system is supported. The improvement process is continuous. The new project will be started when new functionality will be needed.

CONCLUSIONS

The main objective of the work is achieved.

The novelty of the work is the development of IDSS vision. Selection of IDSS methodology and introduction of possible way for IDSS development was introduced.

Summary of the main results:

1. New vision of interaction of internal and external data circles of a collaborative network of enterprises was developed. The new approach for Internal and External data management process presented.
2. Selection of tasks the IDSS must be able to solve.
3. Selection of methodologies for solving of selected tasks.
4. Testing of methodology by software tools

- Selected and tested methodology for comparing alternatives on strategic level. It is shown how it is possible to rank different alternatives by the use of Analytical Hierarchical Process. Also it is introduced how decision tree method can be used for management decisions support.
- Selected Bayesian methodology for the monitoring of established projects and processes in real time. Bayesian network help to transform information into knowledge. Integrated approach saves time for company management. IDSS enables the tracking of decision-making process, which enables users to study and to better understand the made decision. It is possible to see how the latest information reflects on decision made and how it is possible to perform more effective decisions. It is possible to simulate and assess in which directions the work must be made.
- The vision of operation level management decisions support is proposed. IDSS will be able to support decision making that enables profit maximization in the boarder's of collaboration network. System enables the optimal use of resources in the conditions of existing constrains and decision support for optimal outsourcing.

- Was presented interval based robust decision support approach to support closed loop supply chain management. This model explicitly differentiates uncertainty from variability and incorporates uncertainty factors due to lack of information. Interval probabilities are used to represent classes of possible variations instead of precise ones. This allows considering all possible scenarios between extreme cases during probabilistic reasoning. A generalized Bayes' rule was used for reliable decision making. This new approach enables to improve the robustness of decisions under high uncertainties.

5. The IDSS development methodology is proposed. Input-Output analysis will be performed for the key processes. Then those processes will be implemented into prototype which will be used during the system development process. Implementation process will be divided into several steps, which will enhance the reliability of the future system. The active support after the implementation will enable to track the effectiveness of the system and to add required features constantly. The development of IDSS system is a non stop process, the system will grow together with the requirement of collaborative network of SME-s.

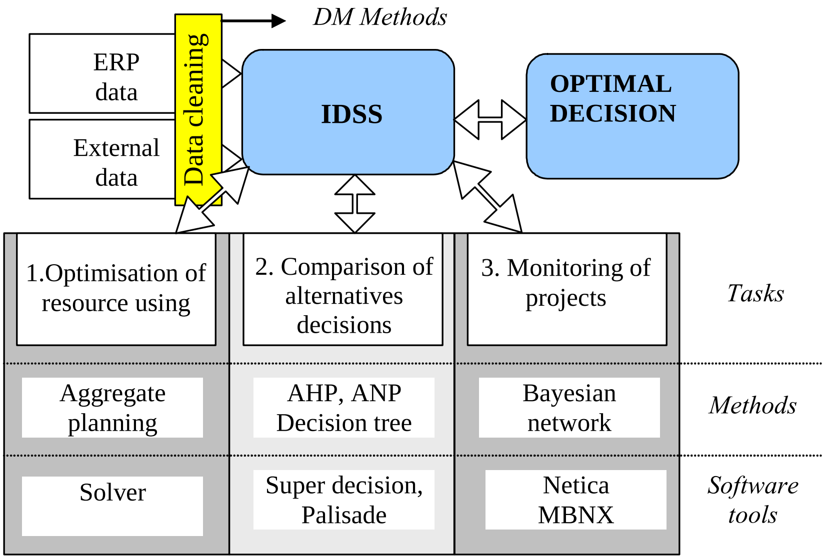

Figure 42. Structure of Intelligent decision support system

The structure of IDSS is shown in the Figure 42. It is important to understand that study is limited to selected tasks. In real life the IDSS development will be a continuous process. New problems will arise, new tasks will be required from the IDSS system, and new method should be selected and integrated in the IDSS.

Future research will be related with quality aspects of collaboration. It is important to describe the quality requirements for subcontractor and the responsibilities of subcontractor.

REFERENCES

[1] Zheng L, Possel.Dölken. Strategic production networks; Springer; 2002.
[2] Gill C, Liestmann V, Bleck S. Strategic management of corporate cooperations 1999, VDI Publishing House, Düsseldorf.
[3] Hirshmann, P.Cooperative design of business processes in corporate networks;Wiesbaden; 1998.
[4] Manufacturing and Services. 8th edition ed.McGraw-Hill, New York.
[5] Chase R, Aquilano N, Jacobs F. Production and operations management: Manufacturing and Services 1998. 8th edition, McGraw-Hill, New York.
[6] Evershei W, Klocke F, Pfeifer, Wech M. Manufacturing Excellence in Global Markets1997. Chapman& Hall, London.
[7] Haegele T, Klink J. The added-value network concept 1998. Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), Stuttgart.
[8] Martin C. Logistics and Supply Chain Managment. Strategies for Reducing Costs and Improving Services1992. Pitman Publishing, London.
[9] Barker R, Dos Santos B, Holsapple C, Wagner W, Wright A. Tools for Building Information Systems. Salvendy G. Handbook of industrial engineering 2001. John Wiley & Sons.USA.
[10] Angus J. BA predicts the Future. InfoWorld 2003; Vol 25; No 34.
[11] Pomerol J, Adam F. On the legacy of Herbart Simon and his Contribution to decision-making support systems and artificial Intelligence. Guisseppi A, Jatinder N, Manuel M. Intelligent Decision-making support systems: foundations, applications and challenges 2006. Springer-Vertlag London Limited.
[12] Hamid R. Taking decisions into the wild: an al perspective in the design of i-DMSS 2006. Guisseppi A, Jatinder N, Manuel M. Intelligent Decision-making support systems: foundations, applications and challenges 2006. Springer-Vertlag London Limited.
[13] Holsapple C, Sena M. ERP plans and decision-support benefits 2007. Decision Support Systems; Vol.38: 575-590.
[14] Nakatsu R. Explanatory power of intelligent systems. Guisseppi A, Jatinder N, Manuel M. Intelligent Decision-making support systems: foundations, applications and challenges 2006. Springer-Vertlag London Limited.
[15] Kolbin V. Decision making and programming 2003, World Scientific Publishing Co. Pte. Ltd.
[16] Far B. Intelligent project lifecycle knowledge management and decision support, *http://www2.enel.ucalgary.ca/People/far/*
[17] Edwards J, Collier P, Shaw D. Knowledge management and its impact on the management accountant. Research report 2005, The chartered institute of management accountants. ISBN 1-85974-569-9.
[18] Wong M, Lee S, Leung K. Data mining of Bayesian networks using cooperative coevolution 2003. Decision Support Systems; Vol 38: 451-472.
[19] Braun P, Brzostowski J, Kersten G, Baek K, Kowalczyk R, Strecker S, Vahidor R. e-negotiation systems and software agents: methods, models and applications. Guisseppi A, Jatinder N, Manuel M. Intelligent Decision-making support systems: foundations, applications and challenges 2006. Springer-Vertlag London Limited.
[20] Brzostowski J, Kowalczyk R. On possibilistic case-base reasoning for selectiong partners in multi-agent negotiation. Proceedings of the 17th joint Australian conference on artificial Intelligence 2005; Springer, Australia

[21] Saaty T. Theory and Applications of the analytic network process: decision making with benefits, opportunities, sosts and risks; 2005.
[22] Zha X, Sriram D. Knowledge-intensive collaborative decision support for design process. Guisseppi A, Jatinder N, Manuel M. Intelligent Decision-making support systems: foundations, applications and challenges 2006. Springer-Vertlag London Limited. RWS publications
[23] Shafiei F, Sundaram D. Multi-enterprise collaborative enterprise resource planning and decision support systems. Proceedings of the 37th Hawaii International Conference on system sciences 2004. 0-7695-2056-1/04.
[24] Themistocleous M, Irany Z. Towards a novel framework for the assessment of enterprise application integration packages. Proceedings of the 36th Hawaii international conference on system sciences 2003. USA.
[25] Sean B. Decision support systems. International encyclopedia of business and management 2nd edition 2001; International Thomson Business Publishing Co, London.
[26] Liberatore M, Nydick R. Decision technology: modeling, software and applications 2002.Wiley
[27] Martin O, Lopez M, Martin F. Artificial neural networks for quality control by ultrasonic testing in resistance spot welding. Journal of material processing technology 2007; Vol.184.
[28] Albright C, Winston W, Zappe C. Decisions making under uncertainty. Data analysis & decision making.2006. Thompson. USA.
[29] Jensen F. Bayesian networks and decision graphs; Springer-Vertlag, New York; 2001.
[30] Bollogu N, Khalifa M, Turban E. Integrating knowledge management into enterprise for the next generation decision support. Decision suppot systems 2002; Vol 33: 163-176.
[31]Hopp W, Spearman M. Factory physics: foundation of manufacturing managent. Irwin/McGraw-Hill; 2001.
[32] R.Küttner. Optimal planning of production mix for subcontracting companies. Proceedings of the 4th International Conference " Industrial Engineering – Innovation as competitive edge for SME" 2004.
[33] De Kort I, Booij M. Decision making under uncertainty in a decision support system for the Red River. Environmental Modeling & Software 2005; Vol.22: 128-136.
[34] Snets P. Belief Functions and the Trensferable belief model. Sipta 2000.
[35] Winkler R. Introduction to Bayesian Inference and Decision. USA. 1972.
[36] Zha X, Sriram R. Knowledge-intensive collaborative decision support for design process. Guisseppi A, Jatinder N, Manuel M. Intelligent Decision-making support systems: foundations, applications and challenges 2006. Springer-Vertlag London Limited.
[37] Nielsed T, Jensen F. On-line systems for production plants: a conflict based approach. International Journal of approximate reasoning 2006.
[38] Spath D, Agostini A. Flexible planning logic for technology planning. Journal of Materials processing Technology 1997; Vol 76: 76-81.
[39] Dey A, Story J. A Bayesian network approach to root cause diagnosis of process variations. International Journal of Machine tools & Manufacture 2005; Vol 45: 75-91.
[40] Kao H, Huang C, Li H. Supply chain diagnostics with dynamic Bayesian networks. Computers & Industrial Engineering 2005; No 49: 339-347.
[41] Deem S. Agent-Based Manufacturing. New York.2003.
[42] Santhanam R, Guimaraes T, George J. An empirical investigation of ODSS impact on individuals and organizations. Decision Support Systems 200; Vol 30.

[43] Riives J, Otto T, Papstel J. Monitoring of technological resources for extended usaga. 4th International DAAAM conference "Industrial Engineering – Innovation as competitive edge for SME"2004.
[44] Maturana F, Norrie. Multiagent mediator architecture for distributed manufacturing. Journal of Intelligent Manufacturing 1996; Vol. 7.
[45] Kondratiev D, Suvorov V. Constructing Federations from Simple Agents and Environment Contexts. Proceeding of SwarmFest 2003, Notre Dame.
[46] Matta A, Semeraro Q. Design of advanced manufacturing systems: models for capacity planning in advanced manufacturing systems; Springer; 2005.
[47] Spraque R, Watson H. Decision support systems. Putting theory into practice; New Jersey; 1986.
[48] Archibald, Russell D. Managing High-Technology programs and projects; Joh Wiley & Sons; New York; 2003.
[49] Archer N, Chasemzadeh F. An integrated framework for project portfolio selection. International journal of project management 1999; Vol 4; No 17: 207-216.
[50] Matthew J, Liberatore, Nydich L. Decision technology: modeling, software and applications 2003.
[51] Taroni F, Aitken C, Garbolino P, Biedermann A. Bayesian Networks and probabilistic inference in forensic science 2006. London.
[52] Musztyfaga M, Skolud B. Advisory system assisting selection of project structures and project tead. Journal of achievements in Materials and Manufacturing Engineering. Vol 20, Issue 1-2, January-February 2007, 551-554.
[53] Dudek-Burlikowska M, Szewieczek. Quality estimation of sale process with usage of quality methods in chosen company. Journal of Achievements in Materials and Manufacturing Engineering, Vol 20, Issue 1-2:531-534.
[54] M. Dudek-Burlikowska, Analytical model of technological process correctness and its usage in industrial company, Journal of Achievements in Materials and Manufacturing Engineering, Vol 15, Issue 1-2, March- April 2006, 107-113.
[55] F.V.Jensen An Introduction to Bayesian Networks, (2000) London ISBN 1857283325.
[56] Stock J, Speh T, Shear H. Many happy (product) returns. Harvard business review 2002; Vol.80; No.7: 16-17.
[57]Stock JR. Reverse Logistics. *Council* of Logistics Management 1992, Oak Brook, IL.
[58] Sachan A, Datta A. Review of supply chain management and logistics research. International Journal of Physical Distribution & Logistics Management *2005*; Vol. 35; No. 9: 664-705.
[59] Murphy PA. Preliminary study of transportation and warehousing aspects of reverse distribution. *Transportation Journa l 1986*; Vol.25; No.4: 12-21.
[60] Thierry M, Salomon M, Nunen J, Wassenhove L. Strategic issues in product recovery management, California Management 1995; 37 (2):114-135.
[61] Carter CR, Ellram LM. Reverse logistics: a review of the literature and framework for future investigation. Journal of business logistics 1998, 19(1):85-102.
[62] Tibben-Limbke R. Life after death: reverse logistics and the product life cycle.
International journal of physical distribution and logistics 1998; Vol.132; No.3: 223-244.
[63] Ravi V, Ravi S, Tiwari MK. Analyzing alternatives in reverse logistics for the end-of-life computers: ANP and balanced scorecard approach. Computers & Industrial Engineering 2005;48:327-356.
[64] Tan A, Kumar A. A decision-making model for reverse logistics in the computer industry. The international journal of logistics management 2006; Vol.132; No3: 331-354.

[65] Kara S, Bugrungruang F, Kaebernick H. Simulation modelling of reverse logistics network. International journal of production economics 2007;106:61-69.
[66] Walley P, Statistical Reasoning with Imprecise Probabilities; Chapman & Hall London;1991.
[67] Dempster A. Upper and lower probabilities induced by a multivalued mapping.Annals of Mathematical Statistics 1967; 38(2): 325-339.
[68] Shafer G. *A Mathematical Theory of Evidence*. Princeton University Press, Princeton, NJ,1976.
[69] Molchanov I. *Theory of Random Sets*. Springer, London; 2005.
[70] Zadeh LA, Fuzzy sets as a basis for a theory of possibility. *Fuzzy Sets Systems 1978*, **1**(1): 3-28.
[71] Dubois D, Prade H. Possibility Theory: An Approach to Computerized Processing of Uncertainty, Plenum, New York; 1988.
[72] Ferson S, Nelson RB, Hajagos J, Berleant DJ, Zhang J, Tucker WT, Ginzburg LR, Oberkampf WL. Dependence in probabilistic modeling, Dumpster-Shafer theory, and probability bounds analysis 2004; SAND 2004-3072: unlimited release.
[73] Nielsen DT, Jensen VF. On-line alert systems for production plants: a conflict based approach. International journal of approximate reasoning 2006; doi:10.1016/i.ijar 2006.06.010.
[74] Spath, Agostini.A. Flexible planning logic for technology planning. Journal of Materials Processing Technology 1997;76:76-81.
[75] Dev S, Story JA. A Bayesian network approach to root cause diagnosis of process variations. International Journal of Machine Tools & Manufacture 2005; 45:75-91.
[76] Kao HY, Huang CH, Li HL. Supply chain diagnostics with dynamic bayeasian networks. Computers & Industrial Engineering 2005; 49:339-347.
[77] Patel G, Li J, Bose S, Timmer D, Gonzalez M. Reverse Logistics: Problems, Framework, Models, and Applications*. Proc. of IERC'06, Orland; FL*; 2006.
[78] SEAN, B. Decision Support Systems, International Encyclopedia of Business and Management 2nd Edition, Edited by Malcolm Warner, International Thomson Business Publishing Co., London, 2001
[79] Berger J.O, Insua D.R, Ruggeri F..Robust Bayesian Analysis.; Springer, New York; 2006.
[80] Walley P. Measures of uncertainty in expert systems. Artificial Intelligence 1996; 83: 1-58.
[81] Bradshaw JM. An introduction to sotware agents. Software agents, MIT press, Cambridge, MA.
[82] Wang Y, A New Paradigm for Developing Intelligent Decision-making Support Systems. Intelligent Decision-making support systems: foundations, applications and challenges 2006. Springer-Vertlag London Limited.
[83] Gachet A, Haettenschwiler P. Development process of Intelligent decision-making support systems: review and perspective. Guisseppi A, Jatinder N, Manuel M. Intelligent Decision-making support systems: foundations, applications and challenges 2006. Springer-Vertlag London Limited.
[84] Ferber J. Multi-agent systems. Addison-Wesley. 1999

LIST OF PUBLICATIONS

The present dissertation is based on the following papers, which are referred in the text by their Roman numerals I-V. As some of the resent research have not been published yet, this thesis was somewhat enlarged.

Journals

I. Kramarenko S, Shevtshenko E, Karaulova T. IDSS as a tool for project management in a collaborative network of sme-s. Journal of machine engineering, March 2007.

II. Shevtshenko E, Karaulova T, Kramarenko S, Wang Y. IDSS used as a framework for collaborative projects in conglomerate enterprises. The extended issue of the worldwide journal of achievements in materials and manufacturing engineering, May 2007.

III. Shevtshenko E, Karaulova T, Kramarenko S, Wang Y. Manufacturing project management in the conglomerate enterprises supported by IDSS". Preaccepted by the Programme Committe of the COMMENT 2007 Conference to be publish in: international journal of materials and product technology (IJMPT).

Refereed Proceedings

IV. Shevtshenko E, Kyttner R. MRP systems research. Proceedings of 4th International Conference of Daam Estonia, industrial engineering - innovation as competitive edge for sme., Editors J.Papstel/ B.Katalinic 29-30April 2004,Tallinn Estonia. ISBN 9985-894-59-6.

V. Shevtshenko E, Kyttner R. Itelligent System for engineering and production planning for collaborative sme-s., COMMENT Worldwide Congress on Materials and Manufactung Engineering and Technology.16-19 May 2005, Gliwice-Wisla, Poland ISBN 83-915011-3-2.

VI. Shevtshenko E, Karaulova T, Kyttner R. Intelligent Decision Support System as the tool for optimization of engineering and production planning for collaborative sme –s., 50. Internationales Wissenschaftliches Kolloquium Technische Universität Ilmenau 19.-23. September 2005, ISBN 3-932633-98-9.

VII. Shevtshenko E, Kyttner R, Karaulova T. Using of multi-agents in intelligent decision support system for collaborative sme -s. NordPLM 06 1st Nordic Conference on Product Lifecycle Management January 25-26 2006 Chalmers University of Technology, ISBN 91-975079-3-8.

VIII. Shevtshenko E, Karaulova T, Kyttner R. Development of IDSS for collaborative network of production enterprises. Proceedings of 5 th International DAAAM Baltic Conference industrial engineering - adding innovation capacity of labour force and entrepreneur 20 - 22 april 2006, Tallinn, Estonia, ISBN 9985-894-92-8, refereed/indexed by isi proceedings.

IX. Shevtshenko E, Kyttner R, Karaulova T. Intelligent Decision Support System as a tool for decision support in collaborative network of sme. Proceeding of IIE Annual conference. May 20-24 2006. USA, Florida, Orlando.

X. Karaulova T, Kramarenko S, Shevchenko E. Knowledge management for network of enterprises. In: Proceedings of the 17th International DAAAM Symposium: (Toim.) B Katalinic. DAAAM International Vienna, 2006, 197 - 198.

XI. Shevtshenko E, Karaulova T, Case study of decision making for collaborative network of sme-s. Proceeding of 2007 Industrial Engineering Research Conference. May 19-23 2007. USA, Tennessee, Nashville.

Approbation

International conferences

1. The 4th International Conference "Industrial Engineering - Innovation As Competitive Edge for SME", DAAAM International Conference, Tallinn, Estonia, April 29-30, 2004.
2. Worldwide Congress on Materials and Manufactung Engineering and Technology " COMMENT"., Gliwice-Wisla, Poland 16-19 May 2005.",50.
3. Internationales Wissenschaftliches Kolloquium".Ilmenau,Germany 19-23, September 2005.
4. 1st Nordic Conference on Product Lifecycle Management "NordPLM 06", Göteborg, Sweden January 25-26.
5. The 5 International Conference "Industrial Engineering - adding innovation capacity of labour force and entrepreneur" DAAAM International Conference, Tallinn, Estonia 20 - 22 April 2006.
6. „IIE Annual conference and Exposition." 2006, Orlando, USA, May 20-24, 2006.
7. „Engineous Software Inc. Users Conference", Orlando USA March 12-14, 2007.
8. „IIE Annual conference and Exposition." 2007, Nashville, USA, May 19-23, 2007.

Authors contribution

The author of this thesis took part in sample preparation routine, was responsible for carrying out of the computational experiments, collecting, processing and further analysis of computational experiments data (Paper I-VI) The author also took part in discussion on the content (Paper VII,) .However, the intellectual merit which is the result of the framework where (Paper VIII – XI) the contribution of every author should not be underestimated.

ABSTRACT

In the real conditions of Estonian economy, there is a trend towards implementing new technologies in production and service sectors. For this purpose, it is important to start up a research project in the area of enterprise collaboration, and to determine the aspects that could be usable under Estonian conditions. Collaboration should increase the competitiveness of Estonian market on EU markets, due to the use of additional possibilities and resources achieved through the collaboration. The concurrency of enterprise network over single enterprise is as much stronger, as concurrency of team over a single person. In this research work, the existing structures of collaboration will be analyzed and new collaboration possibilities will be proposed on the basis of result's analysis.

The research addresses the needs of Collaborative Network of production enterprises. The main idea is that there must be an intelligent decision support system in the network of collaborative enterprises, which will be able to work with different Enterprise Resource Planning systems and different databases that are used in the enterprise network. The role of the human will be to assess the proposals prepared by the systems and to make the decisions; the role of the system will be to suggest the best solutions, which will be based on current conditions.

The novelty of the work is the development of IDSS vision. Selection of methods for decision support and introduction of possible way for IDSS development was presented.

New vision of interaction of internal and external data circles of collaborative network of enterprises was developed. The IDSS system will give new level of importance to the data extracted from ERP system and enhance management of decision support process. The IDSS system can be used to support different kinds of decisions in the collaborative network of production enterprises.

KOKKUVÕTE

Tänapäeva globaalsetes turutingimustes peab iga tööstusharu ja ettevõte olema paindlik, muutustele aldis ning suuteline väljastama toodangut laias nomenklatuuris lühikese aja jooksul madalama omahinnaga [1]. Ettevõtetes on siiski palju infot struktureerimata kujul (tabelid, diagrammid, raportid jne), mis teeb tootmisprotsesside efektiivse juhtimise keeruliseks.

Ettevõtted vajavad metoodikat ja tarkvara, mis võimaldab tootmist efektiivsemalt planeerida ja juhtida. Autor pakub selle saamiseks intellektuaalset otsuste toetamise infosüsteemi ettevõtete koostöövõrgutikule.

Intellektuaalne süsteem hakkab toetama ja haldama andmevooge sise- ja välisringides. Ta võimaldab kiiresti koguda vajalikku informatsiooni ja valida vastavaid vahendeid parema otsuse vastuvõtmiseks. Ta võimaldab kasutajatele süstemaatiliselt uurida mittestruktureeritud probleeme. Süsteemi põhiosad on näidatud joonisel 41.

Otsuste toetamiseks kasutati erinevaid metodoloogiaid:

Tootmisressursside optimeerimiseks maksimaasle kasumi saamiseks kasutati lineaarprogrammeerimist. Arvutusliku eksperimendi baasil on näidatud, kuidas on võimalik kasutada lineaarprogrammeerimist ettevõtete võrgustiku ressursside optimeerimiseks. Kasutati "Solver for MS Excel" tarkvara. Arvutusliku eksperimendi eesmärk on leida ettevõtete koostöövõrgule võimalusi kasumi suurendamiseks tootmisressursside optimaalse kasutamise kaudu.

Kõige keerulisem raamistik sotsiaalse, riigi ja korporatiivsete otsuste tegemiseks on "Analytic Network Process (ANP)", mis on tänapäeval otsuste tegijatele kättesaadav. Ta võimaldab arvestada kõiki faktoreid, kättesaadavaid materiaalseid ja immateriaalseid kriteeriume, mis mõjutavad parema otsuse saamist. Samuti võimaldab "Analytic Network Process" arvestada seoseid ja tagasisidet nii sisese kuid ka väliste klastritega. Selline tagasiside salvestab kõige paremini inimkonna keerulisi efekte, eriti siis, kui on tegemist riskiga ja ebamäärasusega. "ANP" annab võimaluse sisestada hinnangut ja mõõtmisi, et paika panna kaalude rida otsustega distributsioonile. Kaalude rida võimaldab paigutada ressursid vastavalt saadud prioriteetidele ja on seotud faktorite ja faktorite gruppide seostega [23].

Järgmises arvutuslikus eksperimendis on näidatud "ANP" rakendus ("Super Decisions") projektide prioriteetide arvestamiseks. Intellektuaalne otsuste toetamise süsteem võtab arvesse järgmised parameetrid: puhas kasum, diskonteeritud rahavoog, sisemine kasumi tase, esialgse investeeringu taastoomine, keskmine investeeringu kasumlikkus, tagasimakse periood ja eeldatav tasuvus. Kõigepealt loodi 2 klastrit: parameetrid ja alternatiivid. Parameetrite klaster sisaldab sõlmi, mis on seotud parameetritega, millest me oleme huvitatud, alternatiivide klaster sisaldab eriprojektide sõlmi.

Selleks et muuta informatsiooni teadmisteks, on kasutatud "Bayesian Networki". Integreeritud lähenemine säästab firmajuhtkonnale aega. Intellektuaalne otsuste toetamise süsteem ("IDSS") võimaldab otsuse tegemise protsessi jälgimist, mis aitab kasutajatel paremini aru saada tehtud otsustest. Loodud mudel võimaldab jälgida, kuidas viimane kättesaadud info mõjutab meie projekte ja kuidas on võimalik jõuda efektiivseima otsuseni. On võimalik simuleerida otsustamisprotsessi, et aru saada, mis suunas töö peab olema tehtud. Arvutusliku eksperimendi abil on näidatud, kuidas informatsiooni kogumiseks on võimalik kasutada intellektuaalset otsuste toetamise süsteemi (“IDSS”) koos majandustarkvaraga (“ERP”), puhastada ja analüüsida informatsiooni, hinnata ja jälgida tootmisprojekte [55]. Arvutuslikus eksperimendis “Bayesian Network” koostamiseks on kasutatud tarkvarasid “Super Decisions” ja “Microsoft Bayesian Belief Network”.

On uuritud andmete analüüsi vahendeid otsuste tegemiseks tööstusettevõtete koostöövõrgustikus. On pakutud algoritm informatsiooni valimiseks DM meetodite abil.

Töö peaeesmärk on saavutatud. Töö uudsus on intellektuaalse otsuste toetamise infosüsteemi nägemus. Teostati eriprobleemide otsuste toetamise arvutuslikud eksperimendid, et näidata, milliseid otsuseid probleemi lahendamiseks pakutud süsteem on võimeline lahendama.

Saavutatud tulemused:

On välja töötatud uus nägemus sise- ja välisinformatsiooni ringide koostoimimiseks, uus lähenemine välis- ja siseinforingide juhtimiseks, intellektuaalse otsuste vastuvõtmise mudel (“IDSS”) ettevõtete koostöövõrgustiku juhtimiseks.

On näidatud, kuidas intellektuaalne otsuste toetamise süsteem võimaldab toetada efektiivset koostööd ettevõtete vahel.

Pakutud metodoloogia alternatiivide võrdlemiseks strateegilisel tasemel. Tehtud projektide, tarnijate, toodete jne võrdlus ning valitud parim alternatiiv. Näidati, kuidas süsteem teeb informatsiooni kättesaadavaks ja toetab otsuste tegemist eksisteerivate tõkete tingimustes. Süsteem toetab grupi otsuseid ebamäärastes tingimustes. “ANP” (“Analytic Network Process”) teooria on valitud otsuste tegemiseks.

Käivitatud projektide jälgimiseks reaalajas on välja pakutud kasutada Bayesiani metodoloogiat. Süsteem on võimeline jälgima projektide seisu vastavalt viimati saadud infole. Süsteem töötab jälgimisrežiimis ja teavitab kasutajat situatsiooni muudatustest.

On välja pakutud lähenemine robust decision support, et toetada suletud reverslogistika ringide otsuste tegemist. Selle teostamiseks on kasutatud reeglit generalized Bayesian. Kasutatud lähenemine võimaldab parandada tehtud otsuste stabiilsust.

On pakutud metodoloogia “IDSS” loomiseks, juurutamiseks ja arendamiseks. Metodoloogiat katsetati Eesti laevaehituse ja toiduainetööstuse ettevõtete näitel.

APPENDICES

APPENDIX 1

CURRICULUM VITAE

1. Personal data

   Name Eduard Shevtshenko

   Date and place of birth 03/06/1976

2. Contact information

   Address Ehitajate tee 5, 19086 Tallinn Estonia

   Phone +37255655085

   E-mail eduard.shevtshenko@ttu.ee

3. Education

Educational institution	Graduation year	Education (field of study/degree)
Tallinn 26 Secondary School	1990	Secondary-level education
Tallinn High Technical School	1995	Automotive
Tallinn Technical University	1997	Mechanical Engineering/bakalaureus
Tallinn Technical University	2003	Industrial engineering and management / M.Sc

4. Language competence/skills (fluent; average, basic skills)

Language	Level
English	Fluent
Estonian	Fluent
Russian	Fluent

5. Special Courses

Period	Educational or other organisation
2004–2007	Microsoft Business Solutions

6. Professional Employment

Period	Organisation	Position
11.1995–04.1999	Elcoteq Tallinn	Shift manager
04.1999–04.2000	Index Net	Quality manager
04.2000–07.2000	Eesti Telefon	Data connection engineer
07.2002–09.2003	Helvar Merca AS	Product manager
Since 09.2003	Tallinn University of Technology	Researcher

7. Scientific work

Modeling and analysis of manufacturing processes and dataflows in the collaborative network of SME-s

Rapid Product and Process Realization - theory and methodology

8. Defended theses

Master thesis „Special solution for LAN-to-LAN connections based on DSL technology." Supervisor Vello Reedik.

9. Main areas of scientific work/Current research topics

Intelligent decision support system for the network of collaborative enterprises

10. Other research projects

412L The machinery assets maintenance system devepopment and restructuring of maintenance department

426L Microsoft Axapta consultation

481L Production module implementation project of of Microsoft Navision Attain ERP süstem

519L Implementation of production module prototypes based on the Microsoft Navision Attain ERP system

ELULOOKIRJELDUS

1. Isikuandmed
   Ees- ja perekonnanimi Eduard Ševtšenko

   Sünniaeg ja -koht 03/06/1976 Tallinn

   Kodakondsus Eesti

2. Kontaktandmed
   Aadress Ehitajate tee 5, 19086 Tallinn Estonia

   Telefon +37255655085

   E-posti aadress eduard.shevtshenko@ttu.ee

3. Hariduskäik

Õppeasutus (nimetus lõpetamise ajal)	Lõpetamise aeg	Haridus (eriala/kraad)
Tallina 26. keskkool	1990	põhiharidus
Tallina Kõrgem Tehnikakool	1995	keskharidus
Tallinna Tehnikaülikool	2000	Tootmistehnika /bakaureus
Tallinna Tehnikaülikool	2003	Tootmistehnika ja juhtimine / tehnikamagister

4. Keelteoskus (alg-, kesk- või kõrgtase)

Keel	Tase
Eesti	Kõrg
Inglise	Kõrg
Vene	Kõrg

5. Täiendusõpe

Õppimise aeg	Täiendusõppe läbiviija nimetus
2004–2007	Microsoft Business Solutions

6. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
11.1995–04.1999	Elcoteq Tallinn	Tööjuhtaja
04.1999–04.2000	Index Net	Kvaliteedijuht
04.2000–07.2000	Eesti Telefon	Andmeside inseneer
07.2002–09.2003	Helvar Merca AS	Tootejuht
Alates 09.2003	Tallinn University of Technology	Teadur

7. Teadustegevus

Tootmisprotsesside ja andmevoogude modelleerimine ning analüüs väike- ja keskmiste ettevõtete koostöövõrgustikus
Toodete ja tootmisprotsesside kiire teostamine – teooria ja metodoloogia

8. Kaitstud lõputööd

Magistritöö „Special solution for LAN-to-LAN connections based on DSL technology." Juhendaja Vello Reedik.

9. Teadustöö põhisuunad

Intellektuaalne süsteem otsuste toetamiseks ettevõtete koostöövõrgustikus

10. Teised uurimisprojektid

412L Seadme pargi hooldustööde süsteemi väljatöötamine ja hooldusosakonna töö reorganiseerimine.

426L Microsoft Axapta projekti konsultatsioon

481L Microsoft Business Solutions Navision ERP süsteemi tootmismooduli evitamise projekt

519L Microsoft Business Solutions Navision ERP süsteemi baasil tootmisproto-tüüpide arendusprojekt

DISSERTATIONS DEFENDED AT TALLINN UNIVERSITY OF TECHNOLOGY ON *MECHANICAL AND INSTRUMENTAL ENGINEERING*

1. **Jakob Kübarsepp**. Steel-bonded hardmetals. 1992.
2. **Jakub Kõo**. Determination of residual stresses in coatings & coated parts. 1994.
3. **Mart Tamre**. Tribocharacteristics of journal bearings unlocated axis. 1995.
4. **Paul Kallas**. Abrasive erosion of powder materials. 1996.
5. **Jüri Pirso**. Titanium and chromium carbide based cermets. 1996.
6. **Heinrich Reshetnyak**. Hard metals serviceability in sheet metal forming operations. 1996.
7. **Arvi Kruusing**. Magnetic microdevices and their fabrication methods. 1997.
8. **Roberto Carmona Davila**. Some contributions to the quality control in motor car industry. 1999.
9. **Harri Annuka**. Characterization and application of TiC-based iron alloys bonded cermets. 1999.
10. **Irina Hussainova**. Investigation of particle-wall collision and erosion prediction. 1999.
11. **Edi Kulderknup**. Reliability and uncertainty of quality measurement. 2000.
12. **Vitali Podgurski**. Laser ablation and thermal evaporation of thin films and structures. 2001.
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